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Management of Pinyon-Juniper Woodlands

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PREFACE

I wish to acknowledge the writings of many authors from whom I obtained background information for this manual. The principal sources of information are listed in the "References" section of this publication. Specific references to information in the text are not quoted for ease of reading and understanding by the users of this manual. Scientific names of plants, animals, and birds are not used in the text but are listed in appendix 1.

Every effort was made to make this manual a usable synthesis of current knowledge of pinyon-juniper woodlands. I hope this manual, although general in nature, presents principles that will serve as a basis for better understanding of local conditions and site-specific information.

I also wish to acknowledge the willing assistance of Forest Service scientists and technical personnel in gathering information for and reviewing of this manual. Particular thanks is extended to R. Duane Lloyd and Richard L. Everett of the Intermountain Research Station, James A. Young of the Agricultural Research Service, U.S. Department of Agriculture, and Steven Jenkins of the Biology Department, University of Nevada, Reno for their helpful suggestions and assistance throughout the preparation of this manual.

THE AUTHOR

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RESEARCH SUMMARY

The pinyon-juniper woodlands are extensive in the Western United States and are a valuable renewable resource for many uses: livestock grazing, fuelwood harvesting, pinyon nut gathering, wildlife habitat, and a source for poles, posts, Christmas trees, and other home decorations. Such uses have made the pinyon-juniper woodlands an important part in the historical past of the West, and they remain so today.

Past use and misuse of these woodlands have left many areas in the pinyon-juniper woodlands degraded. Recently, there has been an awakening and a realization of the need for better management of these woodlands by land management agencies. For example, forage production for livestock is low, and although improved grazing management and range improvement technologies have been developed, they are not being used in many areas. Wildlife habitat needs improvement in specific areas of the pinyon-juniper woodlands, but criteria need to be applied as to what areas to improve and what methods to use. More information is needed on watershed characteristics and how the use and management of the woodlands is affecting them. Management for fuelwood production and harvesting needs improvement, and new and unique ways to more efficiently use the potential resource of forest products should be given greater emphasis.

At the Pinyon-Juniper Conference held in 1986 at Reno, NV, knowledgeable scientists from universities and government agencies presented reports forming a comprehensive array of knowledge from which to manage these woodlands more intelligently. The proceedings of that conference and many other sources served as a basis for this manual. The objective is to give land managers and natural resource students a general knowledge, emphazing principles by which they can more fully understand and better manage the pinyon-juniper woodlands.

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THE PINYON-JUNIPER ECOSYSTEM

Pinyon-juniper woodlands occupy more than 47 million acres in the Western United States. The woodlands occur primarily on foothills, low mountains, mesas, and plateaus at elevations from 4,000 to 8,000 ft. In higher mountains, pinyons and junipers usually occur at midelevational levels and may be confined to certain slopes depending on moisture and temperature regimes (fig. 1).

The pinyon-juniper woodlands, as a vegetation type, tolerate a wide range of environmental extremes. Average monthly temperatures can vary from 14 °F in January to 95 °F in July. Frost-free growing seasons average 120 days. Cloudy days are rare and relative humidity is extremely low, resulting in high potential evapotranspiration. Average annual precipitation varies from 10 to 20 inches. Storms tend to be infrequent but can be intense, contributing to rapid runoff and erosion.

Soils of pinyon-juniper woodlands are derived from a variety of parent materials and are typically shallow, well drained, and low in fertility. The typical low vegetation cover and the high proportion of bare soil contribute to highly erodible soil conditions.

The States with extensive acreages of pinyon-juniper woodlands are in the Intermountain area, Utah, Colorado, Nevada, eastern Oregon, and eastern California; and in the Southwest, Arizona and New Mexico.

Among these areas the woodland varies widely with different tree species, different shrub species, and different herbaceous understory. The varied plant communities and habitat types present a vast array of differences within the range of the pinyon and juniper ecosystem.

Figure 1—Distribution of pinyon-juniper woodlands in the Western United States.

In the Intermountain area, singleleaf and two-leaf pinyons (see appendix 1 for scientific names of plants, animals, and birds mentioned in this publication) occur along with Utah, western, and Rocky Mountain junipers as the overstory trees, and the shrub layer is composed of such species as mountain big sagebrush, antelope bitterbrush, and Gambel oak. In eastern Oregon and northeastern California the woodlands are characterized by western juniper with the absence of pinyon.

In the Southwest, two-leaf pinyon dominates with limited distribution of Mexican pinyon in southeastern Arizona and southwestern New Mexico. In the northern and central areas oneseed and alligator junipers dominate, with Utah and Rocky Mountain junipers. The shrub layer is characteristically a mixture of hard-leaf species including manzanita, scrub live oak, and yucca (see appendices 2 and 3 for characteristics of pinyon and juniper species).

Herbaceous understory in pinyon-juniper woodlands varies tremendously both in species composition and cover depending on general area, elevation, and tree and shrub cover. On different sites, cool-season or warm-season grasses with a mixture of forbs may occur.

Pinyon-juniper woodlands consist of relatively few tree species, but stands exhibit considerable diversity in appearance and composition. Some stands have closed canopies of single or many tree species, with little or no understory vegetation. Other stands, in contrast, are open with widely scattered junipers or pinyons or both, with a wide variety of shrubs and herbaceous species in a well-developed understory.

This woodland type can consist of stands of all ages or of one age, depending on the history of the area. Even-aged stands characteristically occur as a result of some catastrophic event such as fire or as a result of clearcutting.

At lower elevations and on drier sites, pinyons and junipers tend to be short and bushy with sprawling crowns, and juniper species tend to dominate most stands. At higher elevations and wetter sites, trees are single stemmed and tend to reach their maximum heights. In these areas, pinyon species tend to be the dominant tree. On high-potential sites, some pinyons and Rocky Mountain juniper may reach heights of 50 ft and stem diameters of 30 inches. Western juniper on good sites may also be a good-sized tree. Site potential may affect composition and growth of understory species as well as tree stand characteristics.

Ecological Effects of Past Use

Historical use of pinyon-juniper woodlands has had a profound impact on stand structure and understory characteristics. Use by early homesteaders was similar in the Southwest and the Intermountain areas with regard to grazing of domestic animals and the use and consumption of woodland products, such as cutting trees for fuel and posts and gathering nuts for food. However, use of the woodlands began in the 1600's in the Southwest following Spanish colonization, whereas in the Intermountain area, settlement did not occur until the mid-1800's. Consequently, grazing impacted and altered the development of plant communities differently in the two regions. The general effect of intensive livestock grazing was to so deplete and weaken stands of grass and palatable forbs that their competitive effect on new and establishing tree seedlings was slight. Further, this impoverished understory vegetation could no longer carry fire. With plant communities in this low seral condition, trees increased in density and encroached onto grassland sites.

The earlier introduction of livestock grazing in the Southwest provided trees with nearly 300 more years of increased competitive advantage over understory species, while in the Intermountain area only 100 years of grazing has occurred. Because of this, stands in the Southwest are likely to be older, denser, and with a wider range of age classes than those in the Intermountain area.

In a similar manner, a major difference in commercial use of the woodlands existed between the two regions. Large acreages of trees were not cleared in the Southwest in the historical past. Heavy cutting was confined to local areas to provide fuel for military installations and to provide railroad ties, structural timbers, and limited fuel for the early mining industry. One area where trees were cut for mining purposes was in the Tombstone Mining District of Arizona.

In the Intermountain area, especially Nevada, vast areas of woodland were cut because of the mining boom during the latter part of the 19th century to provide wood for kilns producing charcoal so vital to the ore-smelting process. Because of wide deforestation of pinyon-juniper woodlands, particularly in Nevada, herbaceous plant communities had an advantage over trees with regard to their development.

Because of past overgrazing and deforestation, a great proportion of the existing plant communities are neither climax or near-climax. The pinyon-juniper communities of today are in a real sense the result of past human activity more than natural ecological processes.

Climatic Factors and Distribution

Pinyon-juniper woodlands occur predominantly on foothills, low mountains, mesas,and plateaus, and form bands of trees along mountain ranges at elevations of 4,500 to 7,500 ft in the Southwest and at slightly higher elevations in the Great Basin. The elevations that these woodlands inhabit are commonly intermediate between the more xeric brush and grass-dominated types found below and the more mesic montane forests, usually ponderosa pine-dominated but sometimes with Douglas-fir, lodgepole pine, or other coniferous species, found above them. However, in the Great Basin paleoecological influences have prohibited development of montane forests. Mountain brush types are found instead. Elevational distribution of trees varies according to precipitation and temperature regimes in specific areas. In general, the lower elevational limits are controlled by limited soil water and upper limits by unfavorable temperatures. In some cases, both lower and upper limits of distribution are established by unfavorable temperature regimes. For example, in the Virginia Range of western Nevada the pinyon-juniper woodlands seem to be confined to a thermal belt above the valley inversions and below the colder upslope elevations.

Elevation appears to be the most important topographic feature influencing climate and, in turn, stand structure and tree size in pinyon-juniper woodlands. Pinyon pines

dominate at higher elevations and junipers at lower. Aspect is confounded by other variables, but usually the more mesic species occupy north-facing slopes and xeric species the southern exposures. There is a tendency for the communities to be restricted to northern aspects in the southern Great Basin and to be equally restricted to southern exposures in the northern Great Basin. However, there are many exceptions. For instance, western junipers are found on all aspects in the northern Great Basin and in northeastern California and eastern Oregon. Also, in the mountains immediately east of the Sierras in Nevada, pinyon- juniper distribution is not restricted by aspect. Distribution is more a reflection of ecological amplitude and response to available soil water and temperature regimes than to a general topographic relationship of the woodlands as a whole.

Soils

Pinyon-juniper woodlands occur on a wide variety of soils derived from a diverse array of parent materials including granites, limestone, volcanics, basalt, sandstone, and mixed alluvium. Soil depths vary from shallow to moderately deep with generally low to moderate fertility levels. Soil textures range from the coarse, rocky, porous types to fine compacted clays. Soil orders that are represented within this woodland are Aridisols, Entisols, Mollisols, Vertisols, Alfisols, and Inceptisols (see appendix 4 for descriptions of soil orders).

Only a few comprehensive soil and soil-vegetation studies have been conducted in the pinyon-juniper woodlands. Most of the present knowledge is only of the most general nature. It is important, however, that more specific knowledge be obtained to use as a basis for classification of vegetation and effective environments in these woodlands. For instance, the soil series, by definition, is a soil classification unit that consists of individual pedons with a high degree of similarity of all properties, indicating a uniform effective environment. It would be highly desirable, at least in localized areas, to classify and map soils to the series level to ensure a more valid basis for habitat type classification.

A comprehensive, Basin-wide, soil-vegetation study conducted in Nevada and Utah indicated that current climate is a more dominant factor than are soils in delimiting the Basin-wide and elevational distribution of pinyon-juniper woodlands. Also, vegetation and soils differ considerably in their response to climate. The present vegetation has had only a minor effect on soil development. This phenomenon often occurs in arid and semiarid climates because of sparseness of vegetation, frequent and rapid erosion, and long periods required for soil development in these environments.

Paleoecological and present evidence indicates that the vegetation zonation of the Great Basin has been much more dynamic than soil development. Because of climatic shifts and the influence of human activities, plant communities have shifted both in terms of elevation and latitude with relative ease and speed. Because of this, some researchers believe that soil classification units and soil diagnostic horizons are of limited value in differentiating synecological divisions of the woodlands over large areas.

However,when localized areas are considered, soil differences can be a significant factor in altering the effective environments of plants. Thus, classification of soils will markedly aid differentiation of range types and will facilitate classification and inventory of pinyon-juniper woodlands.

Inventory and Classification

Pinyon-juniper woodlands are extensive and diverse in stand characteristics. Density, canopy cover, and botanical composition of both overstory and understory vary according to influences of temperature and water regimes. These in turn are influenced by latitude, elevation, topography, aspect, and soils.

INVENTORY AND CLASSIFICATION SYSTEMS

Inventory and classification of the pinyon-juniper woodlands are essential for understanding the complex plant associations enough to intelligently manage for current and future uses of the resource. Uniformity in vegetation sampling techniques will provide consistency in classifying pinyon-juniper plant associations among locations and among agencies as well as in assisting in making reliable management interpretations, using research information efficiently, and exchanging information.

Communities of pinyon-juniper woodlands may consist of an overstory of trees with a simple understory, or they may consist of a tree overstory with a well-developed understory of shrubs and herbaceous vegetation. The nature of vegetation alone in these communities makes it too imprecise to indicate areas of similar environments and to indicate similarity in management response. Because of the difficulty in identifying similar climax pinyon-juniper communities on vegetation alone, classification of communities and their effective environments should take into account climate, soils, and vegetation together. The ideal inventory method, then, would include these three and the factors that affect them. And the most important of such potentially altering factors in pinyon-juniper woodlands is elevation, followed by aspect, slope, longitude, latitude, landform, and geologic substrate.

Meaningful classification can be accomplished when basic climate-soil-vegetation relations are understood. However, these relations are difficult to interpret in pinyon-juniper woodlands because of the simplicity of the vegetation and because the dominant species are wide ranging and have broad ecological amplitude in relation to where they can and cannot grow.

One classification system developed by the Forest Service for Arizona and New Mexico combines climate, soils, and vegetation (Moir and Carleton 1986). On this basis, 70 plant associations with 280 ecological sites can be differentiated in pinyon-juniper woodlands of that area. Another striking example of an inventory and classification system of wildlands based on soil-vegetation relation is the Cooperative Soil-Vegetation Survey in California, which is conducted by the Forest Service, California Division of Forestry, and the University of California (California Department of Forestry 1980). In this survey, soil-vegetation units are classified and mapped. These units are readily

identified, recognizable, and usable in management of forests and rangelands.

Classification systems for pinyon-juniper woodlands should form the physical-biological basis for recommending best use of the woodlands, whether it is to produce wood fiber or pine nuts, to produce forage for livestock production, to provide suitable wildlife habitat, to stabilize watershed and lessen erosion on a specific area, or to combine these objectives.

REMOTE SENSING

Remote sensing, usually consisting of photography from airplanes or satellites, holds much promise in the identification and mapping of vegetation in pinyon-juniper woodlands. Researchers are developing and testing many applicable remote-sensing techniques that, when coupled with computer processing, can be of great value in inventory and classification of pinyon-juniper woodlands. Currently, a valuable application of this technology is to monitor changes in canopy cover or invasion of trees into adjacent communities.

VOLUME AND GROWTH PREDICTION

Land managers administering large acreages of pinyon-juniper woodlands need information on tree volume and growth. They cannot get this information by readily accessible direct measurements. One solution is to use mathematical models to predict volume and growth from readily measurable variables, such as tree diameter, height, and crown dimensions.

Gross cubic foot volume equations are available for pinyon-juniper and several other woodland species in the central Rocky Mountain States including Nevada, Idaho, Utah, Colorado, and Wyoming. The volume equations are based on data collected as a subsample of woodland inventories conducted by Federal and State land management agencies. Use of the equations requires measurement of a tree's diameter at the root collar (DRC), total height, and number of basal stems. Current annual volume growth rate or average annual volume growth rate is best modeled as a function of total crown volume, total basal area growth, and percentage juniper crown cover (see appendix 5 for example volume and growth equations in pinyon and juniper). In addition, a site index equation has been developed from a relationship between tree height and diameter.

PINYON-JUNIPER RESOURCES, USES, AND VALUES

Uses—past and present—of the pinyon-juniper woodlands in the United States reflect the products and values that have changed from one people and their culture to the next people coming to live in or use these resource-rich areas.

Historical Uses

Pinyon-juniper woodlands have been used by people for the past 20,000 to 30,000 years. First, the American Indians used these lands and the products that they yielded. Then the Spanish and southwestern settlers came, and in the 19th century, the miners and ranchers depended on these woodlands for forage, fuel, and building material.

The way of life of the Indians of the Southwest and the Great Basin areas was directly tied to the harvest of pinyon nuts. In many years, their very survival depended on collecting and eating pinyon nuts. For many tribes, a winter without an adequate cache of pinyon nuts was a disaster.

In addition, the Indians of the region extensively used trees from pinyon-juniper woodlands for fuelwood. They used these trees for poles and roof beams and as material to make tools and other domestic implements. The branches were used to construct corrals for trapping wild animals and the pitch from trees was used to make glue for jewelry and for medicinal purposes.

The early Southwest settlers had high regard for the pinyon-juniper woodlands. The pinyon was their traditional Christmas tree. Pinyon and juniper foliage was used as decorations many times a year. These settlers used pinyon and juniper trees for fuelwood and building material for their homes, corrals, and fences.

Perhaps the most important historical use of pinyon and juniper trees in the Great Basin occurred in the mid-1800's when silver was discovered in Nevada. The requirements for firewood and fuel to smelt the ore were staggering, and in much of the area surrounding the mining towns whole forests were denuded. To smelt a ton of ore required 30 bushels of charcoal, which, to produce, took one cord of wood. In a year the hills were bare within 10 miles around the towns and mines, and in 5 years the charcoal makers were forced to travel 50 miles or more to get wood.

Despite the great demand for charcoal in smelting of silver, the use of pinyon and juniper wood for home heating and cooking and fence and corral building on the ranches in the Great Basin probably had a greater overall impact on the woodlands. This extensive use of pinyon-juniper woodlands for fuelwood and posts extended well into the 20th century. It wasn't until after World War I that the Great Basin gradually became dependent on fossil fuels for energy, thereby lessening the demand and use of pinyon and juniper wood.

Present-Day Forest Products

Because of the increased demand and the general awareness of the potentials of the pinyon-juniper woodlands, public land management agencies are placing more emphasis on utilization and revenue return from the harvest of fuelwood and other products that can be gleaned from these woodlands.

FUELWOOD

Today, fuelwood remains the most important forest product derived from pinyon-juniper woodlands. Private individuals and commercial operators cut and haul pinyon and juniper wood in increasing amounts because of the higher price for fossil fuels, especially oil and gas for home heating, and the increasing population of the Western States (fig. 2).

Figure 2—Productive pinyon-juniper woodlands near Reno in western Nevada are used for fuelwood cutting, pinyon nut gathering, and Christmas tree harvesting. (Photos by J. A. Young, Agricultural Research Service, U.S. Department of Agriculture, Reno, NV.)

Some agencies administering pinyon-juniper woodlands have been selling wood harvesting permits since the 1940's. Others have not until more recently because fuelwood cutting and nut gathering have been on a free basis and, apparently, agency policies have varied widely. Also, more important, these woodlands have probably not been considered a usable resource except for grazing.

Results of a recent survey of 20 land management agencies show that 11 have been selling permits for forest products for an average of 16 years. The responses among agencies varied from 3 to 45 years indicating a large disparity of policy. This survey also points out the importance of forest products today in terms of revenue for land management agencies. The sales of these products totaled $900,000 annually, an amount that is not trivial and probably represents a break-even return on the management of these lands.

A recent study of fuelwood cutting in Colorado reports that about 41,000 cords were harvested from woodland trees in 1982. Over two-thirds of this harvest was pinyon, all of which came from dead trees. Also, 22 percent was harvested from live juniper trees. Interestingly, the total deadwood harvest for 1982 from the woodlands represented only 1 percent of the total salvable dead volume available.

Much of the pinyon and juniper harvesting occurs in areas that were chained for land conversion or where road construction has pushed over trees. The accelerated harvesting since the 1970's has depleted much of this supply. Today, people are having to drive longer distances or are forced to cut green trees that require aging before use.

When people are forced to cut green trees for fuelwood harvesting, most want to select larger trees in older stands because the wood can be harvested more efficiently. In like manner, the cutting of pinyon is preferred over juniper because juniper trees with many branches close to the ground are difficult to cut and trim and much effort is expended per tree.

Most of the pinyon and juniper are economically unavailable for fuelwood harvest because of long distances to market or physical difficulties, such as steep slopes or distance from roads. Currently, pinyon-juniper woodlands distant from large population centers are seldom used. For example, the Caliente area of Nevada has an estimated potential harvest of 12,000 cords annually, but only 800 cords are harvested.

Results of a study in northeastern California indicated that harvesting even-aged stands of large western juniper trees for fuelwood was not economically feasible because the nearest market is 120 miles away. When ranchers used the fuelwood locally it was to their economic advantage to cut and harvest junipers and to pack wood home for heating and cooking instead of flicking a switch or turning a knob.

Pinyon is preferred over juniper for fuelwood harvesting not only because it is easier to harvest but because it generally sells for more on the market. In Salt Lake City, UT, pinyon sells for $10 to $15 more per cord than juniper. There are exceptions where juniper is preferred over pinyon. For example, in Las Vegas, NV, many people prefer juniper wood, creating much activity in harvesting it.

The bulk of permits issued by Federal agencies is for private fuelwood harvesting. Families often combine an opportunity for recreation in the out of doors with the cutting of fuelwood. There is a sense of satisfaction derived from harvesting one's own wood and enjoying the fruits of that labor on cold evenings. Although fuelwood harvesting is directly affected by the price of gas and oil for home heating, there are other variables that we must consider when projecting future use of these woodlands as an energy source. The opportunity to get out in the woods either with the family or friends, the esthetic and entertainment values to burning an open fire either in a fireplace or wood-burning stove, and the ever-increasing population in the Western States all have a direct influence on the pinyon and juniper harvest.

In a recent survey, 80 percent of the agencies expecting to generate future revenues on pinyon-juniper woodlands predicted that these would increase slightly in the future. The others expected their income to remain stable over time. These are, in my opinion, conservative evaluations of future trends in the use of the pinyon-juniper woodlands considering population trends, fossil fuel prices, and the people's desire to be out of doors. In Arizona, fuelwood demand increased sharply during the mid-1970's, and an upward trend in use is predicted along with the growth in population.

PINYON NUTS

Pinyon nut harvesting is probably the second most important forest product from pinyon-juniper woodlands both for commercial and noncommercial uses. Each year 1 to 2 million lb of nuts are harvested by commercial operators. In some years the harvest has exceeded 8 million lb. The nut crop is uncertain and tends to be heavy in localized areas so that the average production per acre is meaningful only over a large area.

CHRISTMAS TREES

Christmas trees are an important product of the pinyon forests. Some good Christmas tree harvest sites are in areas that were chained, burned, or otherwise treated 20 to 30 years ago. Both commercial and personal-use harvest of Christmas trees is common, with an estimated 500,000 trees cut annually. Pinyon is the only woodland tree used as Christmas trees. The desired height of trees at time of harvest is 6 to 10 ft. As with fuelwood harvesting, Christmas tree cutting is combined with a recreational outing, and the heaviest cutting is near cities.

POSTS AND POLES

Historically, the use of juniper trees for fenceposts, poles, and railroad ties has been important in the settling of the Southwest and the Great Basin. Today, woodland tree species, predominantly juniper, are often cut for fenceposts. In Colorado there are an estimated 110 million usable corner and line posts in juniper trees on State and private woodlands. Juniper is a durable wood that makes it ideally suited for posts and poles. In a 50-year study at Oregon State University, western juniper was the most durable post. Pinyon is not commonly used for fenceposts.

OTHER PRODUCTS

Results from recent pilot tests indicate that current costs of chipping and hauling are too high to make the production of particleboard or paper from pinyon and juniper

trees economically feasible. Production of cement board, composed of 60 percent cement and 20 percent wood fiber, shows promise for a variety of construction uses when the building industry is strong. The potential for naval stores production from pinyon and juniper is promising because the branches and needles of these trees contain four times more resin than Douglas-fir.

Livestock Grazing

Livestock grazing is a major use of the pinyon-juniper woodlands. About 80 percent of the total area is grazed, supporting 1 to 1.5 million animal unit months (AUM's) of grazing. In 1972, livestock use on woodland ranges in the National Forests of Arizona and New Mexico was 630,000 AUM's for cattle and 140,000 AUM's for sheep. Sheep were once much more numerous, but their numbers have declined drastically since World War II.

Pinyon-juniper woodland ranges have been grazed by domestic livestock for over 200 years, and some have been grazed since livestock were brought by the explorer Coronado in 1540. Historically, these rangelands have been grazed yearlong—and many still are—because of the relatively mild climate, especially in the Southwest. These lands are generally in poor condition and have carrying capacities averaging as low as 0.03 AUM's per acre. In the Southwest, carrying capacity is generally higher than in other areas of the pinyon-juniper woodlands.

The generally low carrying capacity of pinyon-juniper rangelands has been attributed to continuous and often heavy grazing with little or no concern for the needs of the forage and browse plants. Low carrying capacity is also associated with increased tree density and the invasion of trees into grasslands.

Wildlife Habitat

Deer is a dominant animal and the most important game species found in the pinyon-juniper woodlands. In many parts of the West, mule deer depend heavily upon these lands for cover, shelter, and feed during the winter. The deer diet consists of juniper foliage, shrubs, forbs, grasses, and lower plants. The diet composition changes throughout the year. In winter, shrubs and trees make up the bulk of the diet. In spring, the consumption of forbs and grasses increases, making up about half of the diet. In summer, forb consumption increases and grass in the diet decreases, and shrubs and trees remain at about the same level. Juniper foliage intake varies among species and among individual trees.

The most palatable shrubs for deer are antelope bitterbrush, alderleaf or birchleaf cercocarpus, and Stansbury cliffrose. In areas where the only shrub is sagebrush, studies have shown that sagebrush makes up as much as 80 percent of the deer diet in October.

Published information on elk use of the pinyon-juniper woodlands is scarce compared to that for deer. In Utah, elk make considerable use of these woodlands in winter, especially where *Cercocarpus* spp. and other palatable shrubs occur with the pinyon and juniper. Some use of these woodlands has been reported in Wyoming and Colorado. In general, elk are usually found where there is a mixture of shrub species upon which they browse in the winter.

Wild horses use pinyon-juniper woodlands extensively in various parts of the West. Horses graze on south-facing slopes in winter and often eat such shrubs as Stansbury cliffrose, antelope bitterbrush, sagebrush, and rabbitbrush in the fall. Certain rehabilitated areas that have been seeded to grasses are used heavily by horses year round.

Such game animals as desert bighorn sheep, buffalo, and pronghorn antelope are found in the pinyon-juniper woodlands in specific areas and at certain times of the year.

The major predator in these woodlands is the mountain lion, which primarily feeds on deer. Coyotes are also a factor in deer predation. Predators of small animals include bobcats and badgers. Porcupines, rabbits, and small mammals, such as mice, voles, woodrats, and squirrels, also reside in the woodlands.

At least 75 species of birds are associated with pinyon-juniper woodlands. Some are permanent residents and some are summer or winter residents, depending upon location. Among the plentiful birds found in the woodlands are about a dozen raptors including bald and golden eagles, hawks, owls, kestrels, and falcons. Each kind of bird found in these woodlands has one or more characteristic differing from other birds that enables it to survive in competition with the others. These include differences in obtaining food, nesting incubation periods, and other adaptive characteristics.

Both pinyon and juniper trees in the woodlands provide food for many wildlife species that eat the highly nutritious seeds. A mutualistic relationship exists between the trees that produce food and the animals that eat and disperse seeds, thereby ensuring perpetuation of the woodlands.

Juniper berries are more consistently available than pinyon nuts. The berries remain on trees a large part of the year, and they are more resistant to insect destruction than pinyon nuts. For these reasons junipers often invade adjacent plant communities first followed by pinyon. Many species of birds and small animals disperse seeds of pinyon and juniper, providing the seed source for expansion of these woodlands.

Watershed and Hydrologic Values

The hydrology of pinyon-juniper woodlands is complex because it represents a wide range of interactions among local precipitation regimes, past land use or misuse, and varied geomorphological and soil conditions. Hydrologic conditions in the woodlands range from a desirable combination of low-intensity rainstorms, good vegetative cover, and permeable soils to the worst case of steep slopes, poor vegetative cover, and impermeable soils coupled with high-intensity rainstorms. The heterogeneity of vegetation cover alone makes it difficult to generalize as to watershed characteristics and hydrologic dangers. The great variation in soils, with their different infiltration rates, in these woodlands also complicates the hydrology of this vegetation type (fig. 3).

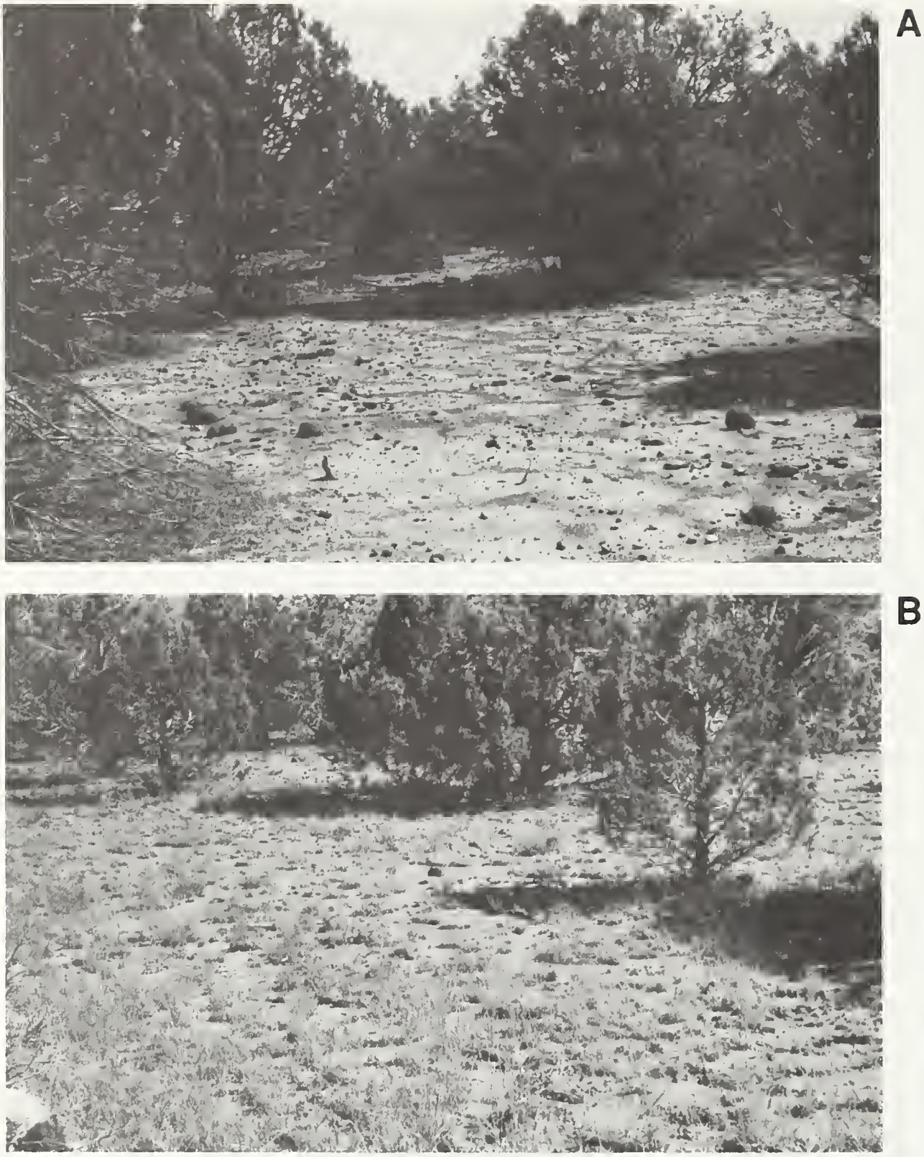

Figure 3—(A) This juniper woodland site in north-central Arizona exhibits extensive sheet erosion. Area is devoid of grass cover even though ungrazed for 20 years. The soil is a clay loam with slow permeability. (B) An adjacent juniper woodland site has grass cover. Note the lack of erosion although this site has similar soil and slope characteristics. (Photos from T. N. Johnsen, Jr., Agricultural Research Service, U.S. Department of Agriculture, Tucson, AZ.)

Total precipitation is relatively low in the pinyon-juniper woodlands. Most storms cause little or no runoff, especially where a combination of desirable hydrologic characteristics exists. However, high-intensity, short-duration storms produce runoff that can be significant when coupled with less desirable hydrologic conditions such as steep slopes, sparse ground cover, and soils of low permeability.

In many cases, the hydrology of pinyon-juniper woodlands is highly sensitive. Excessive rates of runoff and sediment are produced because of overgrazing or other past misuse. Now the prospect for even greater use of the woodlands magnifies the hydrologic problems. The lack of a comprehensive base of knowledge because of the limited research done on the land's hydrology further complicates the watershed picture.

Recreational Activities

More and more people head for pinyon-juniper woodlands for their recreational pursuits. Recreation in these woodlands is as varied as the people pursuing it. People on an outing in the woods to harvest firewood or to gather pinyon nuts, a family claiming their native Christmas tree, the hunter, the birdwatcher, the hiker, and the nature-lover all enjoy these woodlands. More recent recreational pursuits include use of off-road vehicles which exemplifies one of the growing problems in management.

Cultural Values

A dichotomy of cultural values and actions toward the woodlands exists between the American Indian and the

Caucasian. According to archeological findings, the American Indians have lived in harmony with these woodlands for about 30,000 years. During this time, the Indians have sustained themselves by harvesting pinyon nuts and other products from the woodlands for their food and shelter. In all this time, their actions have not appreciably disturbed or changed the character of the woodlands. The Indians would like to see their ancestral homeland left undisturbed or at least used in such a way that the land's integrity would be preserved.

On the other hand, the thinking and actions of Caucasians have evolved, somewhat dramatically, over their short time on these lands through successive waves of people and interests. The pinyon-juniper woodlands were used to a small degree by early settlers, then devastated for much needed fuel and structural material for mining and ranching in the last century. The lands were overgrazed for centuries by domestic livestock, altered drastically for conversion of woodlands to rangelands, then left alone as an unimportant resource. Finally, there is an awakening that these woodlands are a valuable resource and that they should be managed in that light.

ECOLOGICAL RELATIONS BASIC TO MANAGEMENT STRATEGIES

Managers of pinyon-juniper woodlands need to know about such ecological factors as climate-soil-vegetation relations, water relations, or rooting characteristics and nutrient cycling. This knowledge is vital for intelligent management of these lands as a multiple-use resource.

Climate-Soil-Vegetation Relations

Climate, as noted previously, has the most profound effect on the distribution, productivity, and botanical composition of the woodlands. There are three major divisions of climate in the pinyon-juniper woodlands. First, there are two regimes of overall or "macroclimate": (1) the Southwest, Arizona, and New Mexico, and (2) the mountainous West of Nevada, Utah, and Colorado. The Southwest climate is characterized as warm arid or semiarid, while the mountainous West has a cold semiarid climate. The major climatic factor that limits growth and distribution and affects botanical composition and productivity of southwestern pinyon-juniper woodlands is low precipitation while in the mountainous West both freezing temperatures and low precipitation are important.

The local climate or "mesoclimate" of both areas is affected by latitude, longitude, altitude, and aspect (different facing slopes) of the topography. The smallest division of climate is called "microclimate" and is characterized by the regimes of water, temperature, and light that affect individual germinating seeds, seedlings, and plants. Microclimate will be discussed fully in the subsection "Regeneration of Vegetation."

Macroclimates and mesoclimates cannot be altered by management, but because they do profoundly affect the distribution and nature of pinyon-juniper woodlands, a knowledge of their effects on the woodlands is essential for planning and management. In developing a woodland resource management plan, delineation of the sites based on productivity is essential. For instance, highest production sites of fuelwood in the Great Basin are at mid to high elevations on north-facing slopes in the southern part of the area and on south-facing slopes in the north. These sites produce the most because they have the highest effective precipitation and most favorable temperature. Areas to be converted to grassland for livestock production would preferably not be chosen where high productivity of trees is possible and where fuelwood harvest is a viable use in the immediate area. Ideally, a multiple-use land management plan could be established in such areas where tree harvesting on a sustained basis could create conditions for greater forage production for livestock and wildlife.

The influence of mesoclimatic differences as affected by topographic features is seen in botanical composition differences in the pinyon-juniper woodlands. These woodlands occupy all topographic positions in the mountain foothills of both the Southwest and the Great Basin. The pinyons tend to be dominant at higher elevations than junipers, but are often subdominant in other situations. This pattern probably reflects the xeric nature of juniper compared to the more mesic pinyon. The Colorado pinyon-alligator juniper habitat type requires more mesic conditions than does the Colorado pinyon-oneseed juniper type. Alligator juniper does not become an important component of the woodland until elevation reaches 6,750 ft. Apparently, shifting competitive relations are responsible for these differences as the mesoclimate changes with different elevations.

Understory species in the woodland seem to be even more sensitive to topographic variables than are the tree species. For example, in central New Mexico two shrubby species, walkingstick cholla and skunkbush sumac, exhibit opposite responses to topography. Cholla densities are highest on nearly level south-facing slopes. Skunkbush has greatest density and cover on steep north-facing exposures. Wavyleaf oak, another abundant shrub in the area, has greatest canopy cover on steep slopes, but its cover is not greatly influenced by different aspects.

Although soils are diverse in these woodlands, they play a secondary role to climate in the distribution and nature of the woodlands. In instances where the soils are shallow and rocky or have an impermeable pan or horizon in their profile or a vesicular crust on their surface, their water-absorbing and water-holding capacities are low, thus reducing available water to plants. Where deep, highly organic, friable soils are found, effectiveness of precipitation is increased in terms of water available for plant growth. Soils influence vegetation by altering regimes of available water.

Productivity of soils is related to their fertility level in addition to soil depth, texture, and structure. Soils with relatively high nitrogen levels with adequate phosphorus, sulfur, and other nutrients will be best for production of trees, shrubs, and herbaceous vegetation. The fertility level of soils is dependent on parent material and past and present vegetation on the site. It can be altered by management practices such as burning or tree harvesting.

Unfortunately, detailed information on soils and soil-vegetation relations is not currently available for the pinyon-juniper woodlands. For now, management decisions must be made in relation to soil in a general way only. In the future, information concerning detailed soil-vegetation relations will perhaps be available to management personnel, at least for specific areas.

Water Relations Among Species

Water relations among species are important in determining botanical composition of the pinyon-juniper woodlands and in the selection of revegetation species. The availability of water is the most important limiting factor affecting survival and growth of plants in both arid and semiarid environments. Frequent drought conditions in these areas dramatically impact vegetation responses and land management decisions such as grazing strategies and range improvement.

Morphological adaptations and those based on physiological mechanisms are important to plant drought tolerance. Some of the more important morphological adaptations are deep or widespreading root systems, common in species of pinyon and juniper; sunken or small stomata, characteristic of most conifers (in juniper, stomates are under the scales); small leaf size and reduced numbers of leaves; cuticle formation in the leaf epidermis; presence of water storage tissues, most common in cactus; and leaf folding, rolling, or changes in leaf angle in response to water stress.

Physiological adaptations for drought tolerance include: stomatal control of water loss during periods of stress; alternative photosynthetic pathways, most common example in rangeland plants being the C_4 photosynthetic pathway thought to confer some drought-tolerance capabilities over the more prevalent C_3 pathway; and osmotic adjustment or the lowering of protoplasmic osmotic potential resulting from a net accumulation of solutes in response to water deficits. Osmotic adjustment has been recognized as a significant adaptation to water stress in some native and introduced range plants. Bluebunch wheatgrass, standard crested wheatgrass, western wheatgrass, and blue grama with numerous halophytes are believed to adjust osmotically to water stress, but the ranges of adjustment or details of their functional responses are not yet well defined.

The use of the basic principles of ecophysiology and water relations among plant species will refine our knowledge about species adaptability in managing and revegetating the pinyon-juniper woodlands. By understanding drought-tolerance adaptations, the selection of revegetation species and the breeding of new strains could result in more successful stand establishment and persistence.

In relation to elevation, moisture is probably the important factor controlling pinyon and juniper distribution. Recent study results indicate that pinyon distribution is limited by its physiological tolerance for water stress at lower elevation, more xeric sites. Pinyon is severely disadvantaged on hotter, drier sites. Juniper is more drought resistant than pinyon, photosynthesizing at much lower leaf water potentials, exhibiting lower leaf water potentials in the field, and maintaining a high leaf carbon gain under xeric conditions.

In a study in northeastern Arizona on a pinyon-juniper site and an adjacent one supporting grass and shrubs, mean site water potentials were significantly lower in the shrub-steppe community than in the pinyon-juniper woodlands. However, few abiotic differences were found between the two sites. There was a slight difference in elevation. Vertical structure of the communities was considerably different, which may lead to decreased wind velocity and less evapotranspiration. The difference in vegetation cover may also account for differing rates of water loss among soil horizons.

A study in Nevada gives us clues on why pinyon invades adjacent sagebrush communities. Research found that encroachment of singleleaf pinyon into adjacent communities may be related to the tree's ability to maintain a more seasonally stable xylem water potential and thereby to endure drought better than the associated shrub plants. Pinyon seedlings require a nurse plant to survive. Nurse plants provide shade and moderate microclimatic stress for young seedlings, but they also compete with seedlings for available water and nutrients.

Another aspect of water relations important to managers is how trees in the woodland use water and change the environment. As western juniper woodlands increase, water resources may deteriorate through an increase in sediments, a decrease in subsurface flow, an increase in interception of precipitation, and a reduction of soil water reserves through transpiration. These in turn lead to a decline in shrub, herb, and grass production. Where juniper trees have been removed, there has been an increase in understory production from 50 to 300 percent.

Rooting Characteristics of Plants

Rooting depth and pattern vary widely among plants of different life forms. In a pinyon-juniper woodland in northern New Mexico, roots of perennial forbs and grasses occur mainly within the first 12 inches of the soil surface. Roots of overstory trees were traced to depths of 20 ft along fractures in the rocks. Root systems of shrubs were the most varied, some with distinct and deep taproots to 6 to 8 ft and others with a more extensive root system in the surface layers of the soil.

Nature and depth of root systems of plants are important factors in water relations among plants. Those plants with deep extensive root systems are able to occupy and extract available water from more of the soil volume, an attribute that becomes more important as the dry season progresses in pinyon-juniper woodlands.

Nutrient Cycling

Trees in the pinyon-juniper woodlands accumulate nutrients beneath their canopies as do other arid and semiarid trees and shrubs. Pinyons and junipers extend their lateral roots into open areas between the tree canopies and extract water and nutrients from this soil. By this process, the

Figure 4—Extensive lateral root system of pinyons makes the trees formidable competitors. The root system mines the interspace areas of available soil water and nutrients and prevents the growth of understory vegetation. (Photo by R. L. Everett, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Reno, NV.)

available nutrients are accumulated in the branches and leaves of the trees and are released as litter fall beneath the canopies, thus enriching the beneath-canopy areas and mining or taking from the intercanopy areas (fig. 4).

Invasion of trees into adjacent shrub-grass communities may result in substantial shifts in the distribution of nutrients between living plants and the soil-litter-duff system. This results from the extraction and accumulation of greater amounts of nutrients by trees than by shrubs, grasses, or forbs because the trees have greater biomass and more extensive root systems than these other species.

Chaining followed by piling and burning causes a substantial redistribution and loss of nutrients from pinyon-juniper woodlands. Harvesting fuelwood could also cause large losses of nutrients depending on the type of residue treatment. Elimination of all slash and litter by burning could cause a loss of approximately 13 percent of the total nitrogen in the plant-soil system. In an already nutrient-impoverished ecosystem, a loss of nitrogen of this magnitude could likely result in lower biomass production and might lead to successional changes resulting in invasion and domination of annual weedy species.

Regeneration of Vegetation

Regeneration of pinyon and juniper and their understory depends on condition of the microsite, the presence of nurse plants, chemical reactions of plants to each other and competition among plants. This section gives two examples of succession in the woodlands following disturbance by fire.

PINYON PINE

Good seed production of pinyon pines occurs on trees that are 75 to 100 years old. Maximum seed production probably occurs on older trees (160 to 200 years old). Two-leaf pinyon begins to bear cones at about 25 years while singleleaf pinyon does not produce cones until 35 years. Cones require three growing seasons to mature. Pinyon pines are generally monoecious; that is, they bear both male and female flowers on the same tree. As in other pines, the flowers are wind pollinated. Pinyon seeds are heavy and wingless and are not adapted to wind dispersal. Birds and rodents are probably the main dispersal agents. The relationship between feeding habits of birds and small animals and seed dispersal and germination in pinyon and juniper is an important link in the establishment and maintenance of the woodlands.

Four species of birds are known to eat and cache pinyon seeds. ("Caching" is burying the seeds singly or in clusters in the soil, usually about 1 inch deep, and later coming back to recover at least some of the seeds.) The bird species are Clark's nutcracker, pinyon jay, scrub jay, and Steller's jay. Coadaptation of Clark's nutcracker and pinyon jay with two-leaf pinyon occurs in the Southwest. In good seed years, a flock of 150 Steller's jays can transport 3.3 to 5 million seeds a distance of 13 miles. Pinyon jays, a somewhat smaller bird, can transport 30,000 seeds per day up to 6 miles. The seeds can be cached in the soil (one seed per cache) in openings, under trees or shrubs, or along edges of tree trunks, rocks, or stumps, depending on the species of bird. Some are even cached in crevices on live tree trunks or in rock or stump crevices.

The noted ecologist and conservation philosopher Aldo Leopold once wrote that to remove pinyon jays from the pinyon-juniper woodlands of the Southwest would result in the death of that community. The relationship of the pinyon jay to pinyon pines is so strongly interwoven that it represents one of the best coevolved, mutualistic plant-vertebrate examples known. The trees benefit by the birds

caching their seeds, in desirable germination sites, and the jays benefit from a food high in energy and nutrients.

Pinyon seeds germinate in the spring following snow melt. The fresh seeds have high viability varying between 85 and 95 percent. However, seed viability decreases rapidly in 1 year or less, and the rate of germination is slow. Also, germination is best with moderate temperatures (65 to 75 °F).

Although pinyon pines are intolerant to shade, most seedlings establish under the canopies of trees or shrubs because usually the overstory vegetation is not dense enough to reduce light to a critical level. Favorable conditions of available soil water and moderate temperatures, because of shading of adjacent plants, are vital environmental factors to seed germination and seedling establishment in pinyon.

Singleleaf pinyon seedlings can develop a taproot 6 inches long in 10 days, and seedlings can withstand soil water below the wilting point for about 2 weeks. However, in the field severe drought is common for long periods so seedlings only survive in the most favorable microenvironments.

Shoot growth is extremely slow during the seedling stage and in early years. Shoot growth in singleleaf pinyon is less than 1 inch per year. Because of their slow growth and susceptibility to adverse microenvironmental conditions, pinyon seedlings cannot tolerate competition from grasses and other herbaceous vegetation. Further, young trees are susceptible to fire. Seedling growth is highly dependent on soil nutrient status and is increased by local enrichment under shrubs and trees.

Junipers, which have a broader ecological amplitude in terms of temperature and moisture than does pinyon, seem to invade an area first and are subsequently replaced by pinyon as the community dominant, at least in the more mesic and more favorable areas.

In the Intermountain area, fire is the main natural disturbance in the woodlands. A proposed sere or chain of successional stages suggests that, immediately after fire, annuals invade and dominate. Then shrubs and perennial grasses dominate and are replaced by pinyon and juniper trees. Tree seedlings appear about 30 years after a fire and generally dominate the site in 70 to 80 years.

Many sites rapidly return to woodland after chaining or cabling. This is not from seedling establishment but rather from small trees or whips that are not killed in the rehabilitation process. Sprouting alligator juniper is also common in bulldozed areas.

JUNIPER

Oneseed juniper trees produce seeds when 10 to 20 years old. The fruit is a berry that ripens in August or September the first year after flowering. Large seed crops occur every 2 to 5 years. The seed coat consists of an outer fleshy layer of pectic substances, a thick lignified stony layer, and a thin inner membrane of suberized material. In several junipers the hard seed coat interferes with water uptake. Germination is delayed by embryo dormancy and by impermeable seed coats, immature embryos, or germination inhibitors.

Juniper seed germination is extremely slow. Under laboratory conditions, untreated seeds reached 50 percent germination after 40 days of incubation. When seeds were leached in water for 48 hours, germination reached 85 percent after 40 days. When leached seeds were cold-stratified for 90 days, germination was about 90 percent. The additive effects of these various seed treatments show that seed germination in juniper is not a straightforward process, but one that requires a specific sequence of environmental conditions for successful natural germination and seedling establishment.

In addition, seeding failure is often due to nitrogen and phosphorus deficiencies in the soil. Studies have shown that certain levels of available phosphorus are particularly important for seeding success.

Seed dispersal is mainly by birds or small animals. Rows of juniper seedlings can be seen along fences where birds perch. Apparently, birds ingest juniper berries, and seeds that go through their digestive tract germinate and seedlings become established. Rodent caching of juniper berries is also an important means of local dispersal.

In north-central Arizona, thousands of robins appear at water sources near juniper berry crops, and each bird consumes over 200 berries per day. These birds fly up to 6 miles to roost each evening. Defecation of undigested seeds is common during these long flights. In this way, robins play a major role in recruitment of young trees in the woodlands and in the invasion of trees into surrounding communities.

In Oregon, establishment of western juniper in the field mainly occurs beneath canopies of sagebrush or established junipers. Apparently, woody plants act as nurse plants for juniper seedlings, reducing soil surface temperatures by shading and by providing more favorable growing conditions in relation to available soil water and nutrients. Juniper seedlings may have an advantage over adjacent shrubs because of more stable water potentials thus allowing the invasion of junipers into shrub and grass communities.

UNDERSTORY SPECIES

Antelope bitterbrush is one of the most important shrubs in the pinyon-juniper woodlands. Its seed and seedbed ecology portrays another important example of plant-vertebrate mutualism. Many species of rodents cache and eat the highly nutritious seeds of bitterbrush. Some cached seeds are overlooked when the rodents are retrieving and eating their hoards. These cached seeds are buried to a depth in the soil that creates a favorable microenvironment for seed germination and seedling establishment. General observations and results of specific studies indicate that rodent caching is one of the factors, or possibly the most important factor, in natural regeneration of these shrubs.

MICROSITE CONCEPT IN RELATION TO PLANT ESTABLISHMENT

To better understand relationships between plant establishment and favorable environmental conditions, let us explore the concept of the safe microsite. A safe microsite is a point in the soil or on its surface where environmental conditions are favorable for seed germination and plant establishment and growth at a specific time. Safe microsites modify the environment in their immediate

vicinity to permit germination and establishment. A rough microtopography of the soil surface, a soil surface covered with plant litter and duff, and the shading by plants, a rock, or a twig all create more favorable microenvironments conducive to plant establishment. Seed burial is also important in creating favorable conditions.

The number of plants established is more a result of the number of safe sites, or sites that have a microenvironment capable of supporting germination and seedling establishment, than the number of seeds that are disseminated.

Available water for germination and growth is paramount in the pinyon-juniper woodlands as it is in other communities in arid or semiarid environments. Favorable temperature regimes that allow plant processes to occur and influence moisture conditions of plants are secondary in importance. In certain instances, light intensity and quality are also important in defining a safe microsite. Intensity and duration of wind can be contributing factors. Also a factor is the genetic capability of plants to germinate and establish in relation to the safe sites.

Soil water available for longer periods and temperatures within regimes favorable for germination result from modifications of the microenvironment permitting natural establishment of plants. These modifications and their beneficial effects should also guide any revegetation attempt. After all, a seed that falls or is placed on a bare soil surface will not germinate unless it has special adaptations for such an environment. Seeds of weeds such as Russian thistle or tumblemustard are among the few that possess such adaptations. Seeds buried in the soil, placed in a furrow or depression, covered with litter, or shaded in some way have an infinitely better chance to germinate and establish a plant.

PLANT COMPETITION

Deleterious modifications of the microenvironment can delay or deter plant establishment. These are caused by plant competition and allelopathy. Plant competition may manifest itself by limiting available soil water to a germinating seed or growing plant, or by shading an emerging seedling so it does not get enough light to survive.

In the pinyon-juniper woodlands, available soil water is usually the environmental factor limiting plant establishment and growth. Therefore, available moisture is logically the most important factor in competition among plants.

Some plants compete more effectively than others. Some plants that we classify as weeds in pinyon-juniper woodlands are aggressive alien annuals that by virtue of their rapid seed germination and rapid and prolific growth can extract available soil water quickly and thus deter establishment and growth of other plant species. In the Intermountain area, cheatgrass is among the most adapted alien annuals and is prevalent especially in the early stages of fire succession or following other disturbances when shrubs, trees, and perennial grasses are destroyed.

In areas of western juniper, the alien annual grasses, cheatgrass and wildrye medusahead, dominate after fire or after tree control or harvest. These grasses respond dramatically to the nutrient release, especially available nitrogen, and negate any revegetation attempt using perennial grasses or other forage and browse species without using adequate weed control.

NURSE PLANTS

The value of nurse plants in establishment of pinyons and junipers is critical. The role of shrubs and large trees in aiding seedling establishment is one of creating a safe microsite for seed germination and seedling growth: (1) by shading the immediate area, which lowers temperatures and prevents rapid loss of available water in the soil, and (2) through the accumulation of litter beneath canopies, which improves moisture and temperature relations, provides nutrients to the developing seedlings, and makes the surface soil more friable.

The adverse effects of competition from mature shrubs and trees through shading and reducing available water in the soil profile seemingly are more than offset by the benefits of the altered microenvironment. In many instances, the competitive effects are not a significant factor in this relationship, and the benefits of the nurse plants are manifested in establishment and growth of young pinyon and juniper trees.

ALLELOPATHY

Allelopathy, the chemical inhibition of one plant by another, is one means of restricting establishment of potential competitors. Leachates from juniper and pinyon foliage inhibit germination of associated understory species. Foliage of singleleaf pinyon contains essential oils having allelopathic effects. Field and greenhouse studies indicate that seedling emergence was reduced from seeds buried in the fermentation layer of pinyon and juniper litter. Emergence was not reduced when seeds were buried in the mineral soil beneath the litter layer, and the allelopathic effect of litter affected some species but not others.

Allelopathy plays an interactive role with other environmental factors in creating understory spatial patterns associated with woodland succession. Allelopathy prevents establishment of understory species rather than eliminating established plants, and its effects are probably secondary to drought stress.

When drill seeding in pinyon-juniper woodlands, the seeds must be placed below the litter layer into the mineral soil for successful plant establishment. When seeds are broadcast, species must be selected for their ability to establish in tree litter. Examples of such species are standard crested wheatgrass, alfalfa, and blue flax.

SUCCESSION IN PINYON-JUNIPER WOODLANDS

Succession is the natural replacement of one community by another. In ecological thought in the United States, the direction of succession is considered to be toward climax or a community that can best use environmental factors in a specific climate. Such factors as different soils and their potential to support different plant species complicate succession and the climax vegetation. In pinyon-juniper woodlands, successive stages of vegetation usually contain the same species but in different amounts and dominance of the landscape.

We have previously discussed factors that affect succession and stage of succession in pinyon-juniper woodlands, including past history, disturbance such as wildfires, pattern of use of the woodlands, and different soils and climatic regimes. The driving force of succession is competition among plant species of different genetically controlled capabilities responding to changes of the environment.

Figure 5—In this dense even-aged stand of western juniper in northeastern California, the almost complete tree dominance excludes all understory vegetation, thus creating unsuitable rangeland for domestic livestock and undesirable wildlife habitat. (Photo by J. A. Young, Agricultural Research Service, U.S. Department of Agriculture, Reno, NV.)

Two sequences of secondary succession after fire will serve as examples of succession after disturbance. One is for southwestern Colorado and the other for western Utah.

FIRE SUCCESSION IN SOUTHWESTERN COLORADO

Climax pinyon-juniper forest
↓
Fire
↓
Skeleton forest and bare soil
↓
Annual stage
↓
Perennial grass/forb stage
↓
Shrub stage
↓
Shrub/open tree stage
↓
Climax pinyon-juniper forest

FIRE SUCCESSION IN WESTERN UTAH

Juniper woodland
↓
Fire
↓
Skeleton forest (dead trees) and bare soil
↓
Annual stage
↓
Perennial grass/forb stage
↓
Perennial grass/forb/shrub stage
↓
Perennial grass/forb/shrub/young juniper stage
↓
Shrub/juniper stage
↓
Juniper woodland

In the example for western Utah, the annual stage could be bypassed to some degree on areas having fair perennial herbaceous cover prior to burning.

There are important justifications for a better understanding of succession in managed and unmanaged pinyon-juniper woodlands. The combination of successional stages or states determines how many products can be obtained from the woodlands and how many values they represent. Multiple use is inconceivable without a combination of successional states.

The managers' challenge is to attain a mosaic of successional levels producing the desired vegetation diversity for an appropriate combination of uses. An unbroken tract of dense woodland produces little besides wood products, and an area cleared and seeded to standard crested wheatgrass supplies little besides cattle forage. However, a combination of these two and their edge effects can be a valuable multiuse resource.

Expectations about succession and its various stages are anticipated in all silvicultural and range management prescriptions. When this concept is clearly perceived and acknowledged by writers and users of such plans, the predicted outcome can be realized.

A large portion of the pinyon-woodland type is exhibiting undesirable successional tree superdominance. In many areas, this could lead to increased soil erosion, eradication of understory plants, the threat of large-scale fires, and site degradation (fig. 5).

MANAGEMENT STRATEGIES AND PRODUCTION ALTERNATIVES

The pinyon-juniper woodlands, growing in areas that are more xeric than any other timber type in the United States, have unique silvicultural characteristics. Also, the demand for products other than wood in pinyon-juniper woodlands, particularly forage for livestock and wildlife habitat, may provide many opportunities to practice multiple-use silviculture. Watershed and recreational values also need to be considered by land managers.

Management for Forest Products

Much of the pinyon-juniper woodlands are presently under custodial management, and large areas are likely to remain so for a long time because slopes are too steep or productivity is too low to justify intensive management. However, there are many areas of woodland that can and do produce fuelwood, poles and posts, and pine nuts, and perhaps in the future, other forest products.

To exert the proper control of harvest and growth in these woodlands we need to know:

1. How much do we have?
2. How fast does it grow?
3. How can it be regenerated?
4. How is it to be utilized?
5. How does forest product production relate to other uses?

How do we get answers that we can use for the management of pinyon-juniper woodlands? The three steps to consider are inventory, growth projection, and harvest scheduling through a planning model.

INVENTORY

In recent years, a fairly rapid development of inventory techniques has included LANDSAT satellite data, aerial photos, line intercept transects, and fixed or variable plots with equations developed for woodland segmentation procedures. Despite such technological progress, construction of volume equations for pinyon and juniper trees still presents unique problems.

Unlike most conifers, excessive branching and multiple basal stems appear to be normal growth patterns for pinyons and junipers. A variety of measurements have been tried to ascribe quantitative values to the bushy growth characteristics of these trees, including crown and stem variables in volume equations and conventional variables of trunk diameter and tree height. Recently, volume equations have been formulated for much of the pinyon-juniper woodlands based on measurements of tree diameter at the root collar (DRC), total height, and the number of basal stems. They apply to most of the pinyon and juniper species found in woodlands of many States, in addition to several other tree and shrub species.

Because of the diverse growth forms and the tremendous variability of trees from site to site, these generalized equations give volume prediction errors up to 20 percent, and in specific instances they may be even less reliable. For large-area surveys such as on a State basis, they do provide adequate reliability. Development of local volume equations for each application is perhaps the best means to obtain precise volumes of pinyon-juniper woodlands. This would be fairly simple by subsampling trees from an inventory for volume by visual segmentation. A regression volume equation can then be developed reflecting the diverse tree forms in the specific area.

A comprehensive inventory consists of more than just plot-taking techniques and volume estimates. Meaningful information must be developed that will permit projection of growth and estimation of changes in size or age classes as time passes. At present, Forest Service cover typing differentiates major aspects of pinyon-juniper woodlands, such as juniper woodland, oak woodland, pinyon-juniper, and Rocky Mountain juniper. Size classes used for pinyon and juniper are nonstocked, seedlings and saplings (4 inches tall to 2.9 inches diameter at root collar, DRC), small trees (3.0 to 8.9 inches DRC), and large trees (more than 9.0 inches DRC).

Additional useful information includes accessibility, stocking, and slope classes. Some measure of site quality and potential is desirable because of the broad range in productivity that exists in the pinyon-juniper woodlands. Sites vary in their potential from ones that can support little more than juniper shrubs to those that produce trees more than 30 inches in diameter. Management on such diverse sites will differ greatly.

Results of a study in Arizona, New Mexico, and southern Colorado indicated that tree height-age site index curves were useful in predicting volume when used with stand density. This study also indicated that height-age site indices could be used for developing growth equations for individual tree species in the woodlands.

GROWTH PROJECTION ESTIMATES

Growth projection estimates have used various measurements including basal area at 1 ft above the ground, volume and age, and height and age. Regardless of methodology used, estimates must be made on how various strata in the woodland will change with time. The volume and growth of each stratum provide needed information for a harvesting schedule.

Growth is dramatically affected by site quality and stocking. Productivity ranges from 2 ft^3 to more than 30 ft^3 per acre per year on well-stocked, good sites. A productivity level should be determined at which some sites should be excluded from management for periodic fuelwood cutting and others retained for fuelwood harvesting.

The growth projection should also form the basis for the management regimes and rotational ages that will be used in harvesting schedules. Harvesting schedules also include types of harvesting that are to be done on specific areas.

SILVICULTURAL PRACTICES

Past management emphasis of pinyon-juniper woodlands has primarily been to modify the woodland overstory to increase forage production for livestock grazing. As a result, little is known about the silvical characteristics, proper stocking levels, silvicultural systems, or cutting methods that are best suited for pinyon and juniper regeneration and stand management. But silvicultural techniques do apply and should be implemented in these woodlands. However, no one silvicultural system of harvesting is best for all land management situations, and local conditions and needs should dictate the methods used. The land manager should select the most appropriate silvicultural technique to meet both land management direction and the tree species silvical requirements.

A silvicultural system includes the entire process by which woodland stands are tended, harvested, and replaced. The system includes all cultural practices performed during the life of the stand such as regenerative cutting, fertilizing, thinning, improvement cutting, and using improved seeds and seedlings in a rehabilitation process. Silvicultural systems can be distinguished as either even- or uneven-aged.

Even-Aged Systems—An even-aged silvicultural system results in a stand of trees that are about the same age. By definition, the difference in age of trees will not usually exceed 20 percent of the rotational age. The rotational age can vary from 160 to 240 years depending on the management objectives. The two acceptable cutting methods used in an even-aged system in pinyon-juniper woodlands are clearcut and shelterwood.

The clearcut method, cutting the entire stand, is used when regeneration is relatively certain either naturally or by artificial planting. Natural regeneration in most pinyon and juniper stands is not reliable because of the infrequency of good seed years and years with weather conditions conducive to good germination and seedling establishment. Further, both pinyon and juniper trees have large wingless seeds that deter adequate seed dispersal.

In many instances, however, the success of clearcutting regeneration is markedly increased by leaving some trees, seed dispersal by birds and rodents, leaving slash to moderate the soil surface conditions for better seed germination and seedling growth, and in stands of the sprouting alligator juniper.

With stand clearcutting there is immediate control over the size and shape of the future stand that can be manipulated to meet management objectives, especially to create a shrub-grass-forb seral stage for livestock use and a diverse wildlife habitat. Clearcutting is the simplest method to use, requiring the least amount of silvicultural skill, sale preparation, and administrative time. Important disadvantages are that natural regeneration is not assured and the site is exposed to direct insolation and wind and water erosion.

The shelterwood method is implemented in two or more steps, the seed cut and the removal cuttings, over a period of up to 40 years. The seed cut is when all merchantable trees are removed except the best and the biggest, which are used as sources of seeds for regeneration and to shelter developing seedlings. Later, the removal cut is made when the seed trees are cut to improve growing conditions for the newly established seedlings and saplings by removing the sheltering big trees. The number of seed trees usually left is between 25 and 100 per acre. Site quality and desired regeneration stocking are two factors that will influence seed tree spacing.

An option is also available in the removal or final cut to leave some seed trees for pine nut production if pinyon pine is present in the stand.

The two-step shelterwood cutting method requires more skill than clearcutting and involves higher costs of marking leave seed trees and sales administration. In some instances, the stand will become overstocked before the removal cut is made. Advantages of this cutting method include good control over site conditions for natural regeneration, good site and soil protection, and stand appearance that is esthetically more acceptable than other methods.

Uneven-Aged Systems—Uneven-aged silvicultural systems involve the manipulation of stands to simultaneously maintain continuous high forest cover, recurring regeneration of desirable species, and an orderly growth and development of trees through a range of sizes. Stands that are managed under uneven-aged systems do not have an established management rotation age. Management objectives are met by controlling size and number of trees. There are two regeneration cutting methods that develop and maintain uneven-aged stands: single-tree and group-selection cutting.

With single-tree selection, less desirable trees from specific size classes are periodically removed to regulate and improve stands of trees. This method works well for woodland regeneration and growth but requires a high degree of skill to use.

The group-selection cutting method removes small groups of trees over the entire stand with size of cutting areas held to areas small enough to assure protection from surrounding trees. This cutting method does not work well in pinyon-juniper woodlands because the groups of cut trees are small and difficult to track.

SLASH MANAGEMENT

The methods of slash management are influenced to a high degree by the ecological principles discussed earlier. Prescribed burning clears the area of slash, releases nutrients, and kills weed seeds. It also bares the soil creating a clean seedbed for drilling of seeds of revegetation species. In the burning process, some nitrogen is lost to the atmosphere, depending on the temperature of the fire. However, more nitrogen is made available by the burning process and subsequent nitrification. Other nutrients are released without loss.

Prescribed burning to remove slash could deter natural establishment of plants by baring the soil and creating harsh seedbed conditions on the soil surface. In some instances, an area could be open to increased wind and water erosion. Many of these deleterious results can be avoided by burning under cool, moist conditions in the winter or spring. Under such conditions the fire will burn at lower temperatures and slowly move along the ground consuming most of the accumulated material.

Studies in Nevada indicate that slash left to gradually decay after fuelwood cutting has several advantages. A favorable seedbed is provided for germination and seedling establishment by the accumulated slash on the soil surface. However, in some instances the litter might be too heavy for the seeds to penetrate to the soil surface, so they become perched in the litter exposing them to desiccation. The gradual decay of litter will permit the slow release of nutrients and retard nitrogen loss. Additionally, slash cover of the soil surface provides a degree of erosion protection. An important disadvantage of letting slash accumulations gradually decay after fuelwood harvesting is the temporary fire hazard that this accumulated material presents. However, the degree of flammability from accumulated slash is much reduced after the first year because the needles have dropped from the branches.

Slash removal by burning is easier in areas that have been clearcut. In other harvesting methods, more care is required in prescribed burning, such as piling most of the heavy material and burning the piles individually and broadcast burning the rest of the area under safe conditions so the remaining trees are not harmed.

Management for Forage and Browse Production

Managers need to consider two aspects of production of forage and browse in the pinyon-juniper woodlands. The first is the control of trees and shrubs. The second is the revegetation of shrubs and herbaceous species, including the deterrents for their favorable establishment.

METHODS OF TREE AND SHRUB CONTROL

The principal methods of tree control for increased forage and browse in the pinyon-juniper woodlands are mechanical—chaining, cabling, bulldozing, fuelwood harvesting without regard for regeneration, tree crushing, and variations and combinations of these; fire, either by rehabilitating after wildfires or using prescribed burning; and chemicals—the use of herbicides, either on an individual tree basis or by an areawide application.

Mechanical Control—Since 1950, about 550,000 acres of pinyon-juniper woodlands on the National Forests in the Southwest have been mechanically treated to improve forage production. Over 500,000 acres were chained for tree control by the Bureau of Land Management (BLM) in the Western United States between 1960 and 1972. In addition, many acres of pinyon-juniper woodlands on private property have been converted to grazing land by mechanical means.

Pinyon-juniper woodland conversion work in general has received less and less emphasis in recent years. For example, pinyon-juniper chaining by the BLM peaked at about 80,000 acres per year in 1967, dropped sharply to about 35,000 acres annually in 1968 and 1969, and after that has been steadily declining.

Evaluations of BLM projects in the Intermountain area showed that chaining-windrowing-drilling was the most costly but most effective method of converting pinyon-juniper woodlands to grassland. The least effective and most inefficient method was chaining alone because it released too many young trees.

Because of the inefficiency of chaining and the fact that so many of the woodlands were converted by chaining, today these areas should be re-treated if forage production and the resultant carrying capacity is to be improved. In fact, close to 80,000 acres of the original 550,000 converted acres in the Southwest have already been re-treated, mostly by bulldozer pushing and individual tree treatment of pelleted herbicide, with some prescribed burning and handcutting.

Fuelwood Cutting—Pinyon pine and juniper are preferred fuelwood species and, in accessible areas, their availability is becoming limited. Between 1977 and 1979, fuelwood sales increased 62 percent. The cutting of trees for fuelwood is an excellent method of tree control. In areas where livestock grazing use and wildlife habitat are land management objectives, clearcutting would be an efficient and inexpensive conversion method.

In many instances, recreational or commercial fuelwood harvesting could be combined with woodland conversion. However, in most instances in such a plan, commercial harvesting of fuelwood is not economically feasible if the city markets are more than 100 to 150 miles away. Longer distances could be justified in specific instances in large metropolitan areas where demand is high.

Prescribed Burning—Ease and efficiency of prescribed burning in pinyon-juniper woodlands depends primarily on the number and species of trees present, nature of the understory vegetation, and weather conditions.

Prescribed burning can be effective in closed stands of pinyon and juniper with 300 or more trees per acre in areas of 14 to 18 inches of precipitation if the proper preparations are made. Closed stands of juniper are almost impossible to burn and require winds of more than 35 miles per hour to carry the fire. Burning in closed stands of trees usually requires large crews for preparation or pretreatment, such as chaining or windrowing, and to ensure that the fire will not escape.

In open tree stands with grass understories, fire kills only pinyon and juniper trees less than 4 ft tall. Moreover, it usually requires at least 600 to 700 lb/acre of fine fuel to carry a fire. Prescribed burning could be used to kill young seedlings or saplings in converted grasslands when the grazing management plan calls for a rested pasture.

Prescribed burning to control trees is relatively easy where mixtures of sagebrush and pinyon-juniper occur, a common community in the Intermountain area. This burning can be done in the spring, under prescribed conditions, and in many instances without firelines.

Studies in Nevada suggest that two types of mixed shrub and tree communities are best for burning. One is the scattered community (9 to 23 percent tree cover) where pinyon and juniper start their influence and begin to dominate the understory. The other is the dense tree community (24 to 35 percent) where trees dominate the site to a great extent. These two types of communities can be burned out of fire season under a certain set of conditions.

An analysis of burns in Nevada indicated that the success of a burn could be predicted accurately (89 percent) by adding the maximum windspeed in miles per hour, the air temperature in degrees Fahrenheit, and the percentage of vegetation cover. With a score of 110 the fire would not burn. Scores between 110 and 125 needed continual re-torching. Scores between 126 and 130 produced fires that carried by themselves and created clean burns. And above 130, conditions were too hazardous to burn (fig. 6).

Herbicidal Control—Much research has been done on the chemical control of pinyon and juniper trees including evaluations of many herbicides with foliar spraying, broadcast application of pelleted or granular forms, and individual tree treatments with pellets or granules. This research was prompted by the fact that severe ecological consequences accompany many pinyon-juniper control methods, and the use of herbicides would offer alternatives that are less disturbing to the plant communities. Also, the use of herbicides offers possibilities for more efficient re-treatment methods without disturbing grasses or other forage plants.

Pelleted picloram and tebuthiuron are being used to kill individual trees, to maintain chained or bulldozed areas, and to restore recently invaded grasslands in southwestern pinyon-juniper woodlands. Pelleted picloram also has been used for western juniper control in northeastern California. Both herbicides work through the soil and are

Figure 6—A self-sustaining, out-of-season burn carries through a dense pinyon-juniper woodland in central Nevada. (Photo by R. L. Everett, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Reno, NV.)

degraded by soil microorganisms and sunlight or growing plants. The hazards to the environment, animals, and people are minimal if label directions are followed.

The most efficient and economical use of herbicides is in controlling saplings or young trees in areas that are being invaded by junipers or pinyons or as a re-treatment after chaining or other land-clearing treatment (fig. 7).

For both herbicides, individual tree treatments are selective because herbicide placement is made directly under the tree. Broadcast applications of either picloram or tebuthiuron will damage or kill susceptible nontarget plants on the treated areas. Established perennial grasses have not been damaged by picloram at recommended rates for tree control. However, similar rates of tebuthiuron can damage cool season grasses.

Picloram is a restricted-use herbicide that may only be sold to certified applicators because of a concern for possible damage to desirable off-site plants, not because of excessive danger to animals or people. Tebuthiuron is a general-use herbicide. Both herbicides are currently registered by the Environmental Protection Agency for controlling junipers and pinyons in Arizona and New Mexico. Picloram is registered for control of junipers in California and Oregon.

Herbicide-use restrictions vary by State, by circuit court case, and by documents prepared under the National Environmental Protection Act. Local restrictions should be checked before chemical control projects are planned.

Where sagebrush and pinyon and juniper trees occur together, the need arises to control the shrubs as well as the trees to lessen competition so that grass and other forage species may establish. This has been done in experimental trials in northeastern California where small junipers were controlled by individual tree application of pelleted picloram and the shrubs by spraying 2,4-D before seeding of grasses and legumes. The recommended rate of 2,4-D (2 lb/acre) was sprayed by ground sprayer to control sagebrush. Because herbicide regulations are constantly changing, check current Environmental Protection Agency registration on chemicals before use.

REVEGETATION OF SHRUBS AND HERBACEOUS SPECIES

In many areas of pinyon-juniper woodlands, the understory vegetation is so depleted because of intense competition from the tree overstory or past overgrazing that any forage restoration project must involve artificial seeding. This step in range improvement involves a far greater risk for success than in areas where there is enough understory vegetation to recover naturally after the overstory trees have been controlled. Many methods have been developed in seedbed preparation and seeding to increase the probability of a successful stand of grass or other forage and browse plants. Improved strains and cultivars of forage species also have been selected or bred to help assure successful stand establishment of a high-producing forage crop.

Safe Microsites for Seedling Establishment—In seeding and seedbed preparation, the ecological principles of the safe microsite underlie any successful method. The seeds must be placed where they will have ample water and favorable temperatures for optimum germination. Then the germinating seedlings need available soil water and favorable temperatures to survive and become established.

Weather conditions in any particular growing season are, of course, the crucial factor in success or failure of a seeding. However, many methods can be used to ameliorate adverse environmental conditions and to better assure seeding success, even in marginal years. On the other hand, some seeding techniques reduce the chances for successful seeding to almost zero in any year. Let us look at some of these seeding techniques and the reasons why they can lead to success or failure.

Figure 7—Controlling small junipers (A) and sagebrush with herbicides and directly seeding grass and legumes into the dead shrubs and trees with a rangeland drill (half-size drill is being used in photo B) greatly increases forage for cattle (C). This practice could be classed as preventative maintenance because, by killing small trees in a shrub community, the manager is avoiding a larger problem of tree dominance of the site in the future.

Drilling of Seeds—Covering the seeds in any type of revegetation is essential to prevent desiccation. After a fire or chaining, the most effective seeding is with a rangeland drill. In seeding of the more arid sites, using the modified arms on the rangeland drill to make furrows and to have a wider row spacing is often beneficial. Dragging of juniper or pinyon limbs with the chain after broadcast seeding is an inefficient way to cover the seeds.

The rangeland drill is a seeding implement using a single disk opener that makes a furrow; and the seed is metered from the seed box and drops through a tube immediately behind the single disk. A chain drag covers the seed that has dropped in the furrow. The rangeland drill is massively built, and each arm is independently attached and suspended so it can ride over rocks and stand up to the rigors of seeding on rough rangelands.

Because of its design, the rangeland drill is not a precise seeding implement. The standard practice is to seed two seeds per inch in hopes of getting one plant established per foot. This is an efficiency ratio of 4 percent. Using a relatively inexpensive seed such as standard crested wheatgrass, this practice has been acceptable. When using expensive seed of native perennial grasses or of specific broadleaved herbaceous plants or browse shrubs, the use of the rangeland drill in some instances becomes economically questionable. However, good stands of grasses and other forage species can be established by adhering to proven drilling procedures and seeding with favorable seedbed conditions.

Use of the land imprinter for experimental seeding on rangelands has given seeding successes comparable to the rangeland drill on rangelands in Oregon. The land imprinter appears to be most useful in combination with broadcast seeding on loose or coarse-textured soils. Experimental seeding methods that may improve success of grass seeding are punch planting, planting pregerminated seed, transplanting, and applying water in the seed furrow. Research to modify a precision seeder from New Zealand is also being conducted.

A study of the economics of seeding techniques conducted in pinyon-juniper woodlands after wildfires in central Utah compared aerial seeding and chaining, drilling with the rangeland drill, and land imprinting. Results indicated that drilling and land imprinting were the only revegetation techniques that could be economically justified based on the increase in livestock grazing values. Any other reseeding would have to be justified on the basis of resource protection or other noncommodity values because of the low rate of success.

Broadcast Seeding—Broadcast seeding usually results in the scattering of seeds on the soil surface where they have little or no chance to germinate. In rare instances, aerial seeding has been successful after a fire because the seed was broadcast almost immediately after the burn into a heavy ash layer. The ash layer gave enough protection for the seed to permit germination and seedling establishment.

With aerial seeding, the chances for success in seeding are drastically reduced when compared with drilling. Many sites in the pinyon-juniper woodlands are in terrain with slopes too steep, too rocky, or inaccessible to ground equipment, even with a track-laying tractor. When faced with these situations, land managers should consider carefully the value of revegetating the site and the physical aspects of the seedbed, especially the amount of ash on the soil surface. Broadcasting seeds on bare, steep slopes is futile. Seeding will be a failure.

Broadcast seeding into unburned slash after tree harvest will at times result in success. However, many variables in this type of operation can lead to failure. First, the seeds have to filter through the slash and litter to the soil surface to have a chance for germination and seedling establishment. Then, where cheatgrass and other annual weeds occur, competition from these plants will deter establishment and growth of the slower growing perennial forage species.

Cheatgrass Competition—In the Intermountain area, cheatgrass, an alien annual grass, has invaded many pinyon-juniper woodlands, and when the tree and shrub overstory is removed, this aggressive grass can virtually dominate the site precluding all attempts to establish perennial grasses and other forage plants without weed control. After a hot fire in the pinyon-juniper woodlands, enough of the seed reserve of cheatgrass, which is mostly located in the litter or on the soil surface, is destroyed. An effective fire in the first year provides a brief time window for successful seeding without cheatgrass competition to suppress establishment and growth of replacement species. Seeding at this time also provides an opportunity to take advantage of (1) a quick release of nutrients, even though some nitrogen is volatilized, for good seedling growth, (2) a virtual elimination of all competing vegetation, and (3) a clean seedbed to operate rangeland drills.

Without a hot burn to destroy cheatgrass seeds, the best way to control this weedy grass in preparation for seeding is by disking immediately followed by drilling. This is best done after emergence and some growth of cheatgrass, in early spring or early fall. The soil should be moist at time of seeding with a good probability of subsequent rains and favorable temperatures for optimum seed germination and seedling growth of the planted species.

Herbaceous Revegetation Species—The use of many of the presently available herbaceous revegetation species, varieties, and cultivars will lead to successful stands with adequate seedbed preparation and proper seeding techniques (fig. 8). In addition, new cultivars have been selected for improved seedling vigor and forage production and to control erosion more effectively. Many of these have been field tested and information gathered on adaptation and performance in the pinyon-juniper woodlands. (A complete list can be found in appendix 6.)

Shrub Seeding and Transplanting—Pinyon-juniper woodlands normally support a diverse understory of shrubs and herbaceous species. The shrub component is important, especially for big game habitat, and should not be overlooked in any conversion or revegetation effort. Mixed seedings of shrubs and herbaceous species are better able to control tree establishment than shrubs planted alone. Conversion of pinyon-juniper woodlands has thus been dependent on the codevelopment of shrub and herbaceous species revegetation methodology.

Figure 8—Cattle grazing is an important use of the western juniper woodlands in northern California and Oregon. This area was cleared and seeded to intermediate wheatgrass. (Photo by J. A. Young, Agricultural Research Service, U.S. Department Agriculture, Reno, NV.)

Deterrents for Shrub Establishment—Such deterrents in degraded pinyon-juniper woodlands include (1) problems with plant establishment, (2) site differences and shrub adaptability, (3) competition of weedy annuals, (4) limited access for revegetation because of steep and irregular sites, (5) inadequate planting equipment, (6) seed quality problems, and (7) animal depredation of planted seeds and emerging seedlings.

Poor and erratic seedling establishment is the primary problem that limits shrub use. In high-value and critical areas for deer habitat, transplanting has been done to better assure stand establishment.

Rodent foraging of planted seeds and eating of established plants can decimate large seedings. Rodents and insects prefer seeds of certain species over others. Shrub species most eagerly sought by rodents include antelope bitterbrush, Saskatoon serviceberry, black chokecherry, and bitter cherry. Seeds of species not eaten by rodents are fourwing saltbush, winterfat, sagebrush, and rabbitbrush.

With antelope bitterbrush, a high-value browse species for deer and cattle, there are many inherent problems that are not encountered in establishing perennial grass. Bitterbrush seed has a cold-moist stratification requirement to break dormancy, water requirements for germination are much more exacting than for perennial grasses, and depredation of the planted seed and established seedlings by rodents is a constant threat.

Bitterbrush establishment from planted seeds requires optimum seedbed preparation including good weed control and precisely controlled seeding conditions. Researchers in Nevada have found that early spring seeding, compared to fall seeding, following a hot fire the previous summer, decreases rodent depredation because it shortens the time between planting and seedling emergence, permits adequate time and promotes favorable conditions to break dormancy, and provides favorable soil water conditions for germination and seedling establishment. Seeding success depends heavily on having average or better than average spring rainfall, and even in these years stand establishment is low but adequate for shrub dominance of a site.

When planting bitterbrush or other shrubs with grass, each should be planted in separate rows or spots to reduce the effects of grass competition on the shrub seedlings. Grass plants grow faster and outcompete shrubs grown in mixtures. Naturally occurring understory herbaceous species influence shrub planting success and natural recovery. The invasion of cheatgrass has reduced shrub seedling survival on many sites in the pinyon-juniper woodlands. As was mentioned before, cheatgrass is an aggressive alien annual possessing strong competitive abilities because of rapid germination and prolific seedling growth, especially when compared with slow-growing shrub seedlings.

Planting equipment and methods are currently inadequate to seed shrubs properly. Consequently, these seeding practices do not reflect the full potential of shrub seedings. The rangeland drill and other implements were designed to seed grasses. Most of the equipment cannot be regulated to control planting depths and seeding rates of most shrubs. Tree control and seeding methods have been limited to a few practices, primarily chaining, burning, and broadcast seeding. These practices favor the shrub species that can be reliably established with minimal site preparation.

Progress in Shrub Development—A number of shrub selections have been made and cultivars developed as forage plants for livestock and big game habitat. Numerous other shrubs demonstrate potential for revegetation in pinyon-juniper woodlands, but most have demonstrated weaknesses in seed germination, seedling establishment, or overall growth.

Ecotypes of basin big, Wyoming big, and mountain big sagebrush with higher palatability and increased protein levels have been selected for the pinyon-juniper environment. Also many collections of antelope bitterbrush exhibit specific characteristics that make them well adapted

to specific sites. Many other shrub species, some found naturally in the woodlands and others from closely related communities, show much promise for revegetation. (A complete list can be found in appendix 6.)

Grazing Management—For livestock grazing in pinyon-juniper woodlands, grazing management is based on the same principles that underlie grazing systems used on all arid and semiarid rangelands of the Western United States. The categories of livestock grazing systems include: continuous, year-long grazing; seasonal grazing; deferred grazing; rotational grazing; and rest-rotational grazing.

As mentioned, continuous, year-long grazing has been and is the most prevalent system for livestock management in the pinyon-juniper woodlands. The main reasons for this type of grazing are that most of these woodlands have been under extensive management and such grazing has provided low-cost forage for livestock operators. Continuous grazing results in undesirable successional changes in rangeland forage. In the pinyon-juniper woodlands, there is ample evidence of disastrous effects of this type of grazing. Now with greater interest in the management of the pinyon-juniper woodlands, opportunities can present themselves for more intensive management including more suitable grazing systems.

Although differing in detail, more intensive grazing management systems have two features in common: a period of rest to allow forage plants to grow undisturbed, and a systematic grazing schedule in different parts of the range. The objectives of these grazing systems are to (1) restore vigor of forage and browse plants, (2) allow plants to produce seed, (3) attain heavier and more uniform utilization, and (4) increase animal production.

In overall planning for management of pinyon-juniper woodlands for more efficient livestock forage and browse production, use of range improvement practices, such as tree control and seeding, should be coupled with intensive grazing systems.

Details of different grazing management systems are given in the sources listed in the "References" section.

Management for Wildlife Values

The role of wildlife habitat is extremely important for pinyon-juniper woodlands. These woodlands afford favorable habitat, including cover and thermal protection, and a dependable food supply for many birds, small animals, deer and other larger animals, and predators.

As we have seen, tree canopies can dominate specific sites and drastically decrease valuable understory vegetation. When understory shrubs and herbaceous vegetation are reduced or eliminated by a heavy tree canopy, habitat and food for deer and other game animals can be restored and increased by tree control and, if necessary, seeding and revegetating the area with desirable shrubs, grasses, and broadleaf herbaceous plants.

In any vegetation management, tree density should be reduced only to specific levels to maintain thermal cover for animals, habitat and food for birds, and an esthetically pleasing area for recreationists. Methods of tree reduction and revegetation have been covered in previous sections. Generally, habitat improvement for livestock grazing and wildlife can and do go hand in hand. Improvement projects can and should be planned not for a single purpose but keeping in mind that the pinyon-juniper woodlands are a renewable natural resource for many uses.

Many so-called wildlife improvement projects in the pinyon-juniper woodlands have resulted in less productive wildlife habitat. What may be beneficial to one class of grazing animals may not necessarily be beneficial to another. First of all, care must be exercised when decisions are made to treat an area. Questions that must be answered when proposing a vegetation manipulation plan to benefit wildlife include: (1) Does the proposed area need additional and improved wildlife values? (2) How much of the area should be treated for optimum benefits for a wildlife species or group of species? (3) When should the area be treated? (4) What methods should be used to obtain desired results and benefits?

As with improvement practices to increase forage and browse for livestock production, specific conditions must be met for successful conversion to a more desired vegetation for deer and other wildlife (fig. 9). In some instances, release of understory shrub and herbaceous species by killing of trees will accomplish the desired results. In other instances, the understory is so depleted that revegetation is necessary.

When seeding forage and browse species the following factors will determine success or failure. The potential productivity of the site, with such factors as soil type and terrain, amount and distribution of precipitation, and potential competition from weedy or undesirable vegetation are paramount in determining what areas to seed. Only species, subspecies, varieties, and selections that are adapted to the site should be planted. Seeding of multispecies seed mixtures is important for wildlife habitat improvement, especially when the area is also to be grazed by livestock. Nutritional quality, quantity, and variety for both livestock and game can be provided and enhanced through mixtures.

Good grazing management of cattle can be used as a tool to enhance big game ranges and to improve wildlife habitat. As a general rule, newly seeded areas should not be grazed for at least 2 years following seeding. Low potential sites and those seeded with slow-developing and slow-growing species may require as many as four seasons of nonuse to develop into productive stands.

Vegetation conversion for deer habitat improvement may be either beneficial or detrimental to other animals and birds. Lagamorphs (cottontails and jackrabbits) generally prefer converted areas because of the increased forage production and quality that results from tree control and revegetation. Results of a study in New Mexico

comparing a cabled area with an undisturbed area indicated that lagamorphs preferred the cabled area during spring, summer, and fall because of increased forage and increased cover in debris and slash piles.

A Colorado study of small mammals and birds in relation to chaining indicated that both abundance and species richness (numbers of species) of mammals increased, with some species increasing dramatically and others decreasing. Varied responses of birds and small mammals suggest that modifications should be made to minimize negative effects of vegetation manipulation.

Impacts on cavity-nesting birds can be lessened by leaving selected cavity trees standing near the perimeter of the chaining. Adverse effects on species commonly associated with edges can be minimized by making the perimeters of chainings irregular, creating an ecotone of smaller trees by using a lighter chain around the edges, and reducing the size of chainings. The use of sunspots (cutting trees in 1- or 2-acre patches separated by an equal space) in conversion of dense woodlands to a more open stand would result in increased forage and browse and in many irregular edges of vegetation (figs. 10-12).

Figure 9—Favorable habitat for deer in pinyon-juniper woodlands is dependent on open areas in the woodlands with browse and forage plants and adjacent cover areas of trees. (Photo by D. A. Klebenow, University of Nevada, Reno, NV.)

Figure 10—Cutting western juniper trees in small circular areas creates sunspots, opening the stand unobtrusively. With subsequent seeding of forage and browse species where needed, sunspots provide favorable wildlife habitat and increase forage for cattle. (Photo by J. A. Young, Agricultural Research Service, U.S. Department of Agriculture, Reno, NV.)

Figure 11—Cutting of trees provides fuelwood to partially offset costs of this labor-intensive range improvement practice.

Figure 12—Sunspots are seeded with perennial grasses, forbs, and shrubs with a half-size rangeland drill with deep-furrow arms. Deterrents to successful seeding in these small areas may include annual weed competition and predation of seedlings by deer. (Photo by J. A. Young, Agricultural Research Service, U.S. Department of Agriculture, Reno, NV.)

Management for Watershed Values

A body of knowledge to guide the management of watershed values in pinyon-juniper woodlands does not exist in a practical, comprehensive form. Indeed, only limited research has been done on pinyon-juniper lands, and current management practices have often resulted from applying information extrapolated from studies in other ecosystems. Nevertheless, given the goal of improving and maintaining watershed condition, effective management of the hydrology on pinyon-juniper lands is required.

Part of the problem comes from classification of the woodlands. Pinyon-juniper woodlands describe a wide variety of vegetation and land conditions. Thus, a prevailing need is for a soil-vegetation classification that enables the transfer of hydrologic knowledge gained from research or practice. However, pinyon-juniper woodlands and their ecosystems are not closely linked with specific soils, geology, climate, or associated plant communities, and this increases the difficulty of extending a successful management practice from one site to another and in generalizing the applicability of specific management recommendations to the woodlands as a whole.

Some site-specific research has yielded guidelines. In addition, work has been done to synthesize hydrologic information from similar ecosystems and to apply it to pinyon-juniper sites. But most current watershed knowledge reflects the concerns of the 1960's and 1970's. Hydrologically, these concerns centered on potentials for increasing water yield and the effects of various woodland conversion strategies. At that time, pinyon-juniper woodlands were viewed as undesirable, representing a barrier to increasing grassland cover. However, this perspective has shifted as these woodlands have come to be recognized as a resource for producing a variety of products and as demand for multiple use has intensified. Thus, managers must consider hydrology of the woodlands and watershed management in light of the conflicting demands for forage,

fuelwood, fenceposts, pinyon nuts, off-road vehicle travel, and other recreational activities.

Current concerns recognize that a major goal of hydrologic management is to improve on-site watershed conditions, such as reducing rates of runoff and sediment production and increasing infiltration rates. Following are some highlights of current knowledge concerning watershed management.

PRECIPITATION

Although total precipitation is relatively low in the pinyon-juniper ecosystem, short-duration, high-intensity rainfall can result in significant erosion from specific sites. Watershed studies at locations in the Southwest and Intermountain areas, although not in the pinyon-juniper ecosystem, indicate the importance of these high-intensity rainstorms. Studies at four Safford, AZ, watersheds indicate 5-minute intensities approaching 8 inches per hour. Results of a study of maximum 2-minute rainfall intensities for 41 stations in Idaho, Utah, New Mexico, and Arizona translate to 5-minute rates ranging from 17 inches per hour at Reynolds Creek, ID, to as high as 42 inches per hour at Alamogordo, NM. These results indicate that the absolute rate of rainfall can overwhelm infiltration capacity of soils. However, the total volume per storm gives land managers an opportunity to apply land treatments to increase surface retention.

For example, contour furrows, pitting, and ripping can all have a significant effect on reducing on-site erosion. Contour ripping to a 24-inch depth on a 6-ft spacing has the initial capacity to retain 1 inch of runoff on site. Using large contour furrows can effectively control up to 3 inches of runoff.

INTERCEPTION

Interception of snow and rain by trees in the pinyon-juniper woodlands can be a significant factor affecting total amount of precipitation hitting the soil surface. Results of an Arizona study indicated that average interception in the Utah juniper type during a single year of measurement was 17.2 percent of the annual precipitation for that year. Also reported in this study were interception values of 0.13 to 0.94 inches for a single high-intensity storm. An interception capacity of 0.2 inches of precipitation would reduce the effective 5-minute intensity by 2.4 inches per hour.

In the western juniper type in northeastern California, a 4-year study indicated that interception was between 15 and 20 percent in an even-aged stand of 40 percent crown canopy. Under the edge of western juniper canopies, interception was about 20 percent, in the middle of the canopy it was 50 percent, and at the trunk interception increased to two-thirds of the precipitation. Interception was the same in all seasons.

A second study in Arizona showed no significant difference between pinyon and juniper throughfalls, indicating that interception by the two trees was similar. No specific studies have been done on interception by litter in pinyon-juniper woodlands, but its effect might be significant in accounting for reduction of the intensity of rainstorms.

Calculated annual interception differences (based on the Arizona data) among three chaining treatments in Utah indicated that the greatest interception would occur in undisturbed woodlands and that the annual interception rates on chained and windrowed or chained with debris in place would be from 30 to 90 percent of interception in undisturbed woodlands, depending on the year.

INFILTRATION

Infiltration studies in pinyon-juniper woodlands have received the greatest amount of attention by watershed scientists. The following is the current state of knowledge.

1. Average measured infiltration rates range from 1.2 to 2.0 inches per hour for soils at field capacity and approximately 2.5 inches per hour for dry soils. Rainfall rates are more than these infiltration rates, indicating that surface runoff will occur.
2. Little difference in infiltration rates exists between undisturbed and chained plots.
3. Increased mechanical disturbance associated with windrowing may result in reduced infiltration.
4. Grazing impacts are detectable for a single season and are cumulative. In one instance, protection of the site from grazing for 4 years was necessary to restore maximum infiltration capacity.
5. Burning appears to reduce infiltration rates.
6. Researchers have encountered difficulty in identifying a consistent set of easily measurable factors that influence infiltration rates.
7. Cryptogamic soil crusts increase surface roughness, increase infiltration, reduce intrinsic permeability, provide soil protection, and are slow to recover from disturbance.

RUNOFF

The pinyon-juniper ecosystem generally produces surface runoff in response to high-intensity, short-duration rainstorms. These storms typically produce high unit area rates of runoff on small areas. One study showed a measured rate of flow of 400 to 700 ft^3 per second per square mile (CFSM). Research also showed a 60 percent increase in peak discharge from a cabled watershed. In the Saliz Watershed in New Mexico, a rate of 1,380 CFSM for the 0.3-mi^2 watershed was reported. The Saliz Watershed was heavily grazed. Significant runoff has not been observed since subsequent tree removal, contour furrowing, and reseeding were completed in 1964. Current information on magnitude and frequency of storm runoff related to specific site conditions is inadequate for design of facilities in pinyon-juniper ecosystems.

SURFACE DETENTION

Pits resulting from cabling juniper have been estimated to retain an average of 0.18 inches potential runoff per storm. Other properly applied mechanical treatments, such as pitting, ripping, contour furrowing, and contour trenching used in combination with clearing can provide detention storage ranging from 0.6 to 3.5 inches or more of runoff.

SEDIMENT PRODUCTION

Sediment production is the primary water quality concern from pinyon-juniper ecosystems. Limited information exists for evaluating differences in sediment production between treated and untreated watersheds. At Beaver Creek, AZ, limited data indicate average annual sediment rates of 0.07 tons per acre in winter and 0.03 tons per acre in summer from untreated watersheds. In contrast, a

cabled watershed produced annual sediment rates ranging from a trace to 1.1 tons per acre.

WATER YIELD IMPROVEMENT

The pinyon-juniper ecosystem produces no significant water yield, and most attempts to increase water yield in this vegetation type have produced only marginal results. Small openings may trap snow and increase water available for plant growth. Vast clearing of pinyon-juniper woodlands may produce the opposite effect because of wind-blowing snow.

WATER HARVESTING

Water harvesting is a management technique that can provide the necessary quantity and distribution of animal drinking water on lands used for livestock grazing. Because livestock grazing is a primary use on many pinyon-juniper lands, water harvesting holds much potential value for proper management of this resource.

Water harvesting is the collection and storage of precipitation from a small catchment area that is topographically modified, chemically treated, or covered with a membrane to reduce infiltration. Although water harvesting is a relatively costly method of water supply augmentation, it nevertheless can be used where other methods, such as wells, spring development, water hauling, and pipelines, are not feasible.

FUTURE TRENDS AND NEEDS

Current use of pinyon-juniper woodlands is expanding. New and innovative practices are needed to respond to these demands while maintaining and improving the productive potential. Maintaining on-site productivity and water quality requires development and application of appropriate management practices. Some of the areas of concern are (1) road location and design to control runoff and erosion, (2) level of constraints or mitigation to control off-road vehicle use, (3) livestock management strategies that provide greatest production with least resource impact, and (4) fuelwood and Christmas tree harvesting to maximize long-term production and maintain favorable watershed conditions.

Successful watershed maintenance and improvement strategies will require resolution of the following:

1. What constitutes satisfactory watershed condition and what can be used to assess it?
2. What influence does high-intensity, short-duration rainfall have on selection of management strategies and their accompanying treatment strategies?
3. Do differences in the spatial distribution of ground cover produce different runoff results? (As an example, is there a difference between 30 percent cover concentrated under trees and 30 percent cover of grass and litter uniformly distributed over the same site?) What role does overstory interception play with respect to short-duration storms?
4. What management strategies are available to deal with vertisols and vesicular soils?
5. What is the current influence of pinyon-juniper woodlands on riparian conditions? What management strategies provide greater protection for riparian and other downstream values?

Management for Recreational Values

Recreational values and activities are highly diverse and varied in the pinyon-juniper woodlands. Managers should keep in mind the needs of the people visiting the woodlands and how they would view the results of certain management and conversion practices, especially those that disrupt the natural setting. Esthetics are important to most people visiting these lands, so in areas where wildlife or livestock management objectives dictate tree removal or other conversion of the woodlands, managers should be aware of how this activity will be viewed. The killing and removal of trees from small, irregularly shaped areas are usually more acceptable to the public than from large rectangular blocks.

Also needed is the continual education of the public about the real nature of the pinyon-juniper woodlands and what agencies are trying to achieve with specific conversion practices that are essential for successful management of these areas. Public understanding and support for management of pinyon-juniper woodlands should be one of the prime objectives of each manager having responsibility for their maintenance.

Custodial Management

Custodial management has been defined as managing to protect existing resource values and prevent further deterioration. A more accurate definition when applied to pinyon-juniper woodlands is the management practice used where none of the other management alternatives such as type conversion for wildlife or livestock, or management for sustained yield of fuelwood or other woodland products, are cost effective. Essentially, as practiced today in the pinyon-juniper woodlands, custodial management is nonmanagement. However, on some public lands there has been a recent trend of moving away from custodial management even though it is to a rather extensive level of maintaining 200 to 400 trees per acre.

Ample evidence suggests that nonmanagement of the pinyon-juniper woodlands leads to site degradation, increased soil erosion, depleted understory production, and a stagnant and unhealthy overstory of trees.

Succession in the pinyon-juniper woodlands favors tree dominance over the understory vegetation, so when these woodlands are not managed, trees become dominant and the understory of shrubs, grasses, and broadleaf plants dies out. Often, this leaves only bare ground under the trees and, in some cases, the skeletons of dead shrubs as the only understory remnant. These are conditions that foster erosion of the top soil and the occurrence of devastating fires that in turn lead to further degradation of the woodlands.

Integrated Management of Overstory and Understory Vegetation for Multiple Uses

The pinyon-juniper woodlands, because of the demand for products other than wood, particularly forage for

livestock and wildlife habitat, provide an opportunity to practice multiple-use silviculture. The management of these lands for multiple use does not mean that every acre should or can be managed in relation to the entire spectrum of uses. Different sites have different potentials for plant growth and a different potential for use. The woodlands that are now used for fuelwood harvesting will probably continue to be important for that use because of location and site potential. Although these woodlands should be managed primarily for fuelwood production and harvest, the cutting of trees often presents the opportunity for increased forage production and improved wildlife habitat as secondary uses and benefits.

Livestock grazing or wildlife habitat are sometimes the primary benefit or management objective of a specific area of pinyon-juniper woodlands, especially where fuelwood harvesting cannot be considered as a current, valid use of the woodlands because of remoteness or inaccessibility. In such areas, judicious tree control should be considered for increased forage production and wildlife habitat improvement.

Much of the pinyon-juniper woodland has low productivity and marginal economic usefulness. These are the lands that should be under custodial management, but even they should be managed, at least extensively, to ensure that the resource is maintained. There are many such lands that are not important for their commodities but are essential for watershed and wildlife values.

SUMMARY

Pinyon-juniper woodlands are made up of many diverse ecosystems in the Western United States. Pinyon and juniper trees grow on many types of soils, on varied topography, and with different climatic regimes. Occurrence and dominance of trees vary over the spectrum of the woodlands, as do understory species.

Not only do we find great diversity in the characteristics of pinyon-juniper woodlands, but uses of these woodlands also vary widely from fuelwood harvesting, providing fenceposts, Christmas trees, and pine nuts to livestock production and wildlife habitat.

These woodlands represent a many-faceted, fragile, ever-changing resource with multiple demands on it for products and uses. Coordinated resource management and planning can provide tools for identifying proper management strategies and alternatives and at the same time will protect resource values and prevent further deterioration of the lands.

The challenge is great for the people charged with responsibility of managing this resource to satisfy the demands made upon it and still preserve it as a viable, productive ecosystem.

The objectives of this manual are to provide an overview of the pinyon-juniper woodlands and to emphasize basic principles for their management to guide managers in making decisions based on the latest information. Because these principles cover an extremely diverse ecosystem, they should be considered only as general guides for the management of particular areas to be supplemented by more specific information and on-the-ground evaluation.

Many published sources detail specific methods for management and improvement of rangelands that can be used in pinyon-juniper woodlands. Some of the more relevant and comprehensive publications are listed in the references section.

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APPENDIX 1: COMMON AND SCIENTIFIC NAMES OF PLANTS, ANIMALS, AND BIRDS (ALPHABETICALLY LISTED BY COMMON NAME)

Common name	Scientific name
PLANTS	
alfalfa	*Medicago sativa*
bitterbrush, antelope	*Purshia tridentata*
bitterbrush, desert	*Purshia glandulosa*
bluestem, little	*Andropogon scoparius*
burnet	*Sanguisorba minor*
cactus	*Opuntia* spp.
cercocarpus, alderleaf	*Cercocarpus montanus*
cercocarpus, birchleaf	*Cercocarpus betuloides*
cheatgrass	*Bromus tectorum*
cherry, bitter	*Prunus emarginata*
chokecherry, black	*Prunus virginiana* ssp. *melanocarpa*
cholla, walkingstick	*Opuntia arborescens*
cliffrose, Stansbury	*Cowania mexicana stansburiana*
Douglas-fir	*Psuedotsuga menziesii*
fescue, sheep	*Festuca ovina*
flax, blue	*Linum perenne*
flax, Lewis	*Linum perrenne lewisii*
galleta	*Hilaria jamesii*
grama, blue	*Bouteloua gracilis*
gramma, black	*Bouteloua eriopoda*
gramma, sideoats	*Bouteloua curtipendula*
juniper, alligator	*Juniperus deppeana*
juniper, oneseed	*Juniperus monosperma*
juniper, Rocky Mountain	*Juniperus scopulorum*
juniper, Utah	*Juniperus osteosperma*
juniper, western	*Juniperus occidentalis*
kochia, forage	*Kochia prostrata*
lovegrass, Boer	*Eragrostis chloromelas*
lovegrass, Lehmann	*Eragrostis lehmanniana*
lovegrass, weeping	*Eragrostis curvula*
manzanita	*Arctostaphylos* spp.
muhly, spike	*Muhlenbergia wrightii*
oak, Gambel	*Quercus gambelii*
oak, scrub live	*Quercus turbinella*
oak, wavyleaf	*Quercus undulata*
orchardgrass	*Dactylis glomerata*
penstemon, Palmer	*Penstemon palmeri*
penstemon, Rocky Mountain	*Penstemon strictus*
pine, lodgepole	*Pinus contorta*
pine, ponderosa	*Pinus ponderosa*
pinyon, Mexican	*Pinus cembroides*
pinyon, singleleaf	*Pinus monophylla*
pinyon, two-leaf	*Pinus edulis*
rabbitbrush	*Chrysothamnus* spp.
ricegrass, Indian	*Oryzopsis hymenoides*
sagebrush, basin big	*Artemisia tridentata* ssp. *tridentata*
sagebrush, mountain big	*Artemisia tridentata* ssp. *vaseyana*
sagebrush, Wyoming big	*Artemisia tridentata* ssp. *wyomingensis*
PLANTS (con.)	
sagebrush, black	*Artemisia arbuscula nova*
saltbush, fourwing	*Atriplex canescens*
serviceberry, Saskatoon	*Amelanchier alnifolia*
skunkbush, sumac	*Rhus trilobata*
thistle, Russian	*Salsola kali tenuifolia (S. iberica)*
tumblemustard	*Sisymbrium altissimum*
wheatgrass, bluebunch	*Agropyron spicatum*
wheatgrass, standard crested	*Agropyron desertorum*
wheatgrass, crested ('Hycrest')	*Agropyron cristatum* x *A. desertorum*
wheatgrass, intermediate	*Agropyron intermedium*
wheatgrass, western	*Agropyron smithii*
wildrye, basin	*Elymus cinereus*
wildrye, medusahead	*Taeniatherum asperum*
wildrye, Russian	*Elymus junceus*
winterfat	*Erotia lanata (ceratoides lanata)*
yucca	*Yucca* spp.
ANIMALS	
badger	*Taxidea taxus*
bobcat	*Lynx rufus*
buffalo	*Bison bison*
cattle	*Bos taurus*
coyote	*Canis latrans*
deer	*Odocoileus hemionus*
desert bighorn sheep	*Ovis canadensis*
elk	*Ceruus elaphus*
horse	*Equus caballus*
jackrabbit	*Lepus* spp.
lagamorph	Order: Lagamorpha
mouse	*Peromyscus* spp.
mountain lion	*Felis concolor*
mule deer	*Odocoileus hemionus*
porcupine	*Erethizon dorsatum*
pronghorn antelope	*Antilocapra americana*
rabbit	*Lepus* and *Sylvilagus* spp.
squirrel	*Spermophilus* spp.
vole	*Microtus* spp.
woodrat	*Neotoma* spp.
BIRDS	
bald eagle	*Haliaeetus leucocephalus*
Clark's nutcracker	*Nucifraga columbiana*
falcon	*Falco* spp.
golden eagle	*Aquila chrysaetos*
hawk	*Accipiter* spp.
kestrel	*Falco* spp.
owl	Families:Tytonidae, Strigidae
pinyon jay	*Gymnorhinus cyanocephalus*
robin	*Turdus migratorius*
scrub jay	*Alphelocoma coerulescens*
Steller's jay	*Cyanocitta stelleri*

APPENDIX 2: CHARACTERISTICS OF JUNIPERS (*JUNIPERUS* SPP.)

Characteristic	Species Alligator *(deppeana)*	 One-seed *(monosperma)*	 Utah *(osteosperma)*	 Western *(occidentalis)*	 Rocky Mountain *(scopulorum)*
Fruit	Brownish with whitish bloom mealy 3-5 seeds	Dark blue soft, juicy 1 seed	Bluish with bloom mealy 1-2 seeds	Blue-black soft, juicy 2-3 seeds	Bright blue whitish coat soft, juicy 2 seeds
Bark	Blackish or gray thick and rough furrowed into plates	Gray fibrous and shreddy	Gray fibrous furrowed and shreddy	Reddish brown furrowed and shreddy	Reddish brown thin, fibrous and shreddy
Leaves	Blue-green with gland dot	Yellow-green with gland dot	Yellow-green without gland dot	Gray-green with gland dot	Gray-green
Branching habit	Short stout trunk with rounded, spreading crown	Several branches curving up from ground much branched snaggly crown	Short upright trunk with spreading branches open crown	Short trunk broad crown spreading branches ragged and gnarled with age	Straight trunk, narrow pointed crown, slender branches
Regeneration	Sprouting, seed	Seed	Seed	Seed	Seed
Distribution-range	Central and Southeastern Arizona; central New Mexico	Central and Southeastern Arizona; New Mexico; south central Colorado	Nevada, Utah, western Colorado; northeastern and central Arizona	Sierras, northeastern California, eastern Oregon, and western Nevada	Colorado, Utah, Idaho, western New Mexico, and central Arizona

APPENDIX 3: CHARACTERISTICS OF PINYONS (*PINUS* SPP.)

	Species		
Characteristic	Two-leaf (*edulis*)	Single-leaf (*monophylla*)	Mexican (*cembroides*)
Needles	2 in bundle; long, stout light green	1 in bundle; stout stiff, sharp pointed; dull gray-green with whitish lines	3 in bundle; slender, flexible, with white lines
Bark	Gray to reddish brown; rough, furrowed with scaly ridges	Dark brown or gray; smoothish, becoming furrowed into scaly plates and ridges	Light gray and smooth
Cones	1.5-2 inches long egg-shaped yellow-brown resinous	2-3 inches long egg-shaped dull yellow-brown almost stalkless	0.75-2 inches long egg-shaped almost stalkless resinous
Seeds	Large, wingless, slightly thick walled, oily	Large, wingless, thin-walled, mealy	Large, wingless, dark brown, thick-walled
Stature	Small, bushy resinous tree with short trunk	Small, rounded, gray-green crown with low horizontal branches, often shrubby	Small, resinous tree with short trunk and spreading crown
Distribution-range	Arizona, New Mexico, Utah, and Colorado widespread	Nevada and western Utah widespread	Southeastern Arizona and southwestern New Mexico limited distribution

APPENDIX 4: SOIL ORDERS FOUND IN PINYON-JUNIPER WOODLANDS

Alfisols—These soils have a profile that is both massive and hard when dry and possess an argillic horizon or layer that water cannot penetrate. Alfisols have water that is held at less than 15 bars during at least 3 months each year when the soils are warm enough for plants to grow.

Aridisols—Soils of this order do not have water available to mesic plants for long periods. During most of the growing season, water is held at above 15 bars and thus unavailable to plants. These soils have well-developed horizons that were formed under low soil moisture and have little or no leaching through the profile. Typical features of Aridisols are lime layers, salt or gypsum accumulations, low organic matter accumulation, and a calcareous profile. They have one or more horizons that may have been formed in the present environment or that may be relicts from a former pluvial period. The surface soil is usually light in color and soft in consistency. Natural vegetation usually consists of shrubs, and a few ephemeral grasses and forbs. Aridisols are the most abundant soil order worldwide and are found in low rainfall areas.

Entisols—These soils have only slight soil development with little or no development of soil horizons. They range from deep sands to stratified river-deposited clays. Entisols are highly erodible.

Inceptisols—These soils are weakly developed but more so than Entisols. Reasons for only slight development may be that they were derived from recent deposits, have parent material that resists weathering, erosion might be fast enough to remove developing soil, or wetness and cold may slow down translocation and weathering to allow the Inceptisol characteristics to persist.

Mollisols—These are mainly dark-colored, base-rich soils that generally have good grass cover. Some of them may have formed under forests. The surface horizon is usually thick, dark in color, strong in structure because of high organic matter, and more than 50 percent saturated with bases. Soils of this order are between Aridosals of arid climates and Alfosols of humid climates.

Vertisols—These clayey soils have deep, wide cracks at some time of the year. In the rainy season the cracks swell shut and in the dry summer they reopen. In arid areas, these soils develop in closed basins or playas. The parent material is high in limestone, marls, or basic rocks, such as basalt. Most Vertisols support grass or other herbaceous vegetation or open forests.

APPENDIX 5: VOLUME AND GROWTH EQUATIONS FOR PINYON-JUNIPER WOODLANDS

Volume Prediction Model

$V = [B_0 + B_1X^{1/3} + B_2S]^3$

where

V = volume of all wood and bark having branch diameters larger than 1.5 inches (ft^3)

X = diameter near root collar (inches) squared times total tree height (ft)

S = 1 for a single-stem tree, 0 otherwise

B_i = coefficients estimated by linear regression using a cube root transformation.

This model uses a cube root transformation to fit visual segmentation volume data collected throughout the central Rocky Mountain States.

Growth Prediction Model

$G = \exp[B_0 + B_1\ln(X_1) + B_2\ln(X_2) + B_3X_3]$

where

G = sum of current annual volume growth (CAI) or sum of average volume growth (MAI)

X_1 = crown volume variable

X_2 = basal area growth or basal area combination variables

X_3 = juniper crown cover variable.

CAI was best modeled as a function of (1) total crown volume, (2) total basal area growth, and (3) percentage of juniper crown cover. Crown volume, the most important variable reflecting photosynthetic potential for a pinyon-juniper stand, was computed from a geometrical formula (ellipsoid or paraboloid) using crown diameter and height measurements. Basal area growth, the second most important variable, seemed to function as a measure of site quality. Percentage of juniper cover distinguishes the amount of juniper compared to that of pinyon on the site.

For modeling MAI, crown volume was the most important variable. The second best variable involved basal area—either basal area divided by median stand age or alone. The third variable was amount of juniper cover.

Equations for both models are from Chojnacky, David C. 1986. Volume and growth prediction for pinyon-juniper. In: Everett, Richard L., compiler. Proceedings—pinyon-juniper conference. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Intermountain Research Station: 207-215

APPENDIX 6: REVEGETATION SPECIES FOR PINYON-JUNIPER WOODLANDS

Sites are so varied in the pinyon-juniper woodlands that information concerning the best adapted species, selection, and cultivar of revegetation species for specific conditions should be obtained from local workshops or from sources listed in the "References" section.

Common name	Improved cultivars, selections, or subspecies
Grasses:	
Wheatgrass, bluebunch	Whitmar, Secar
crested	Hycrest
intermediate	Oahe, Greenar, Amur
standard crested	Nordan
western	Barton, Arriba, Rosanna
Wildrye, basin	Magnar
Russian	Vinall, Bozoisky - Select
Galleta	Viva
Gramma, blue	Lovington, Hachita
black	
sideoats	Vaughn, Niner
Ricegrass, Indian	Nezpar, Paloma
Lovegrass, Boer	
Lehmann	
weeping	
Muhly, spike	El Vado
Bluestem, little	Pastura, Cimarron
Fescue, sheep	Covar
Orchardgrass	Paiute
Forbs:	
Flax, Lewis	Appar
Penstemon, Palmer	Cedar
Rocky Mountain	Bandera
Alfalfa	Rambler
Burnet	
Shrubs:	
Bitterbrush, antelope	Many selections
desert	
Cliffrose, Stansbury	
Winterfat	Hatch
Saltbush, fourwing	Rincon
Kochia, forage	Immigrant
Sagebrush, big	Mountain
	Wyoming
	Basin
Rabbitbrush	

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This manual, intended to be used by land managers, natural resource management students, and users of the woodlands, is a current state-of-the-art summary and compilation of information on the ecology and management of pinyon-juniper woodlands.

KEYWORDS: forest products, range management,wildlife habitat, watershed and hydrology, multiple-use management, recreation, ecosystem analysis, Great Basin, Southwestern United States

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The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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